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Environment Ontario

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The Investigation, Evaluation, and Recommendations of Biomonitoring Organisms for Procedures Development for Environmental Monitoring

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DISCLAIMER

The views and ideas expressed herein are those of the authors and do not necessarily reflect the views and policies of Environment Ontario, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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1.0 INTRODUCTION

Water quality monitoring has progressed through several stages over the past 50 years. Initially it was determined by visual and olfactory descriptions, then basic chemical tests such as the parameters: pH; suspended solids; conductivity; etc. Analytical techniques developed, and the presence and/or absence of contaminants became water quality descriptors. Qualification and quantification of contaminants in water became achievable. To avoid the collection of vast volumes of water to achieve low detection limits for contaminants, indicator organisms as biological integrators became part of water quality monitoring.

A water sample provides a single point in time. An organism living and reproducing in a system reflects : the environmental health of the system; the potential impact the system's components might have on human health; on the health of predators in the system; and on the biota itself.

Biological monitoring or biomonitoring, has become an accepted practice for regulatory agencies in investigating the impact of point and non-point source discharges on receiving streams. Refinements to the biomonitoring approach are needed in order to better define the impacts from: a specific geographic source; a particular group of contaminants; from a specific time period. One organism may respond better than others for solving particular problems. Clams being less transitory than fish, are better in pinpointing specific discharge points. Leeches accumulate and can serve to track chlorphenols, while fish excrete chlorophenols too quickly for monitoring purposes.

A considerable body of information has developed over the past decade on the uses of different organisms as biomonitors. The bulk of the information comes from the marine environment. This information includes: detection of specific contaminants; the identification of suitable monitoring techniques including length of exposure, size of organism, season of use, handling strategies, etc.; transplantation of organisms or use of indigenous species; determining contaminant body burdens as reflections of levels in the water or essential elements for the animal's metabolic and other life processes; the determination of the role of contaminated sediments on aquatic biota.

The intent of this project is to review this work, determine the organism or organisms best understood and best suited for the Ministry of the Environment's biomonitoring programs (as pinpointing contaminant sources), and to recommend additional areas of pursuit with respect to biomonitoring.

The report is divided into sections based on the organisms discussed with a section on specific contaminants. A summary of all freshwater research is outlined in Tables 1 and 2. References to marine literature are included in each section with a literature summary in Appendices 3 and 4. Tables 3 and 4 provide a summary of organisms used with reference to contaminants, exposure, and associated problems as biomonitors. Table 5 provides examples of exposure and accumulation studies for selected contaminants and organisms in the freshwater environment.

2.0 BIOMONITORING

"Biological monitoring can be defined as the systematic use of biological responses to evaluate changes in the environment with the intent to use this as a quality control program." (Matthews et al,1982)

"Effluent biomonitoring includes two basic activities: 1) measurement of the biological properties of effluents, using captive organisms exposed to the effluent in the laboratory or in the environment, and 2) measurement of the effects of effluents on the biological integrity of the receiving waters." (Weber,1981)

There are many such definitions for biomonitoring. This paper deals with the use of organisms in effluent and zone of impact biomonitoring as defined by Weber (1981), where the biological properties of the effluents are measured using body burden levels of specific components, and the organisms have been exposed to the effluent in the environment. The intent of this work is to look for an organism or a number of organisms to be used in particular situations to aid in the evaluation of pollutant impacts on receiving waters. This impact may be a short or long-term one; may not directly impair each component of the biota but produce secondary impairment, (eg. acute toxicity to phytoplankton can reduce the planktivorous fish population, in turn reduce populations of predaceous or sport fish).

An organism must be easy to handle, inexpensive to use, but provide reliable, scientifically defensible data under stated circumstances.
Those responsible for the effluents (industry, STPs, agriculture, etc.) may be required to conduct their own monitoring programs. Therefore, the easiest, most economically feasible techniques must be determined to ensure the simplicity but scientific reliability of the procedure and results.

Aspects of biomonitoring of interest are:

- the transplantation of organisms, or use of indigenous species;
- the caging of organsims;

- the set exposure periods based on contaminants of interest, biological half-lives, uptake and depuration;
- whether the whole organism, or specific tissues can be used for analyses;
- the ability to pinpoint sources of contaminants;
- the possibility of using an assemblage of organisms to answer several questions with respect to contaminant impact.

National as well as international uses of biomonitoring have been examined for this report. The concept of biomonitoring as defined for this project includes the use of indigenous and/or transplanted organisms (usually caged) whose body burden levels of contaminants reflect the surrounding water concentration (water levels may be too low to detect through water analyses) and the bioavailability of the contaminants, and the potential severe impairment of some use of that water body. Contaminant levels determined in a monitoring program must be interpreted taking numerous factors into account , as the choice of using one organism for all monitoring situations must be carefully examined.

The goal : to provide one organism or a combination of organisms with reliable background evidence to support its/their use in a specific situation ie. STP outfall, pulp and paper mill discharge, electroplating discharge zone etc., for a specific contaminant(s) or group of contaminants. The biomonitoring method used must be relatively simple, cost effective and scientifically defensible. It should provide relevance to the state of the aquatic biota and the potential for human health.

Phillips (1973) states that an organism is useful as a biomonitor if it fulfils the following functions:

1. the organism should accumulate the pollutant without being killed by the levels encountered;
2. the organism should be sedentary in order to be representative of the area of collection;
3. the organism should be abundant in the study area;
4. the organism should be long-lived in order to allow sampling of more than one year class;
5. the organism should be of reasonable size, giving adequate tissue for analysis;

6. the organism should be easy to sample and hardy enough to survive in the laboratory allowing depuration before analysis (if desired) and laboratory studies of uptake;
7. the animal should tolerate brackish water; (or various levels of pH)
8. the organism should exhibit a high concentration factor for metals, allowing direct analysis without preconcentration;
9. a simple correlation should exist between the metal content of the organism and the average metal concentration in the surrounding water; (applies to organics as well)
10. that all organisms in a survey exhibit the same correlation between their metal contents (and organics) and those in the surrounding water, at all locations studied, under all conditions.

The advantages of using an "indicator species" or "biomonitoring organism" are:

1) biological availability can be measured directly;
2) time estimates of pollution availability based on uptake and excretion rates can be developed;
3) concentrations are higher in the biota than in water, therefore, the analytical preperation time and project costs can be reduced (Phillips,).

3.0 HISTORY AND USE OF BIOMONITORING WITHIN THE MINISTRY OF THE ENVIRONMENT

The first biomonitoring studies undertaken by the Ministry of the Environment were in the early 1970s. Attempts were made to collecand analyze phytoplankton and zooplankton for contaminant analyses. This was part of the Pollution From Land Use Reference Group's (PLUARG) mandate in studying the agricultural impact of Southwestern Ontario on the Great Lakes and nearshore biota . Analytical techniques were not well established and sufficient representative samples difficult to obtain, making plankton collections for biomonitoring purposes impractical(personal experience).

The Toxicity Unit of the Ministry of the Environment's Water Resources Branch began collecting young-of-the-year spottail shiners (*Notropis hudsonius*) along the shores of the Great Lakes in 1975. This was to establish a baseline of contaminants data for trend and spatial monitoring. The spottail shiner is an important forage species of the Great Lakes basin , known to spawn over sandy shoals (Scott and Crossman,1973). Composites of 10 fish provide adequate tissue for organic or metal analyses. They have proven to be good indicators of organochlorine contaminants, dioxins, furans and some heavy metals (Karl Suns, personal communications). A good database determining temporal and spatial trends of contaminants in the Great Lakes of Ontario has been developed.

Collections of yearling yellow perch (*Perca flavescens*) began in the province's inland lakes in 1977. Yellow perch are ubiquitous, easy to capture and age, and of a size such that composites of 8 to 10 provide an adequate analytical sample for contaminant monitoring. They have proven to be useful indicator organisms (Karl Suns, personal communication).

The Ministry of the Environment in conjunction with the Ministry of Natural Resources has had an ongoing sport fish contaminant program in Ontario for eleven years. Although the program began to provide the public with areas where fish were suitable for human consumption rather than as a biomonitoring program, a secondary benefit has been its use as an indication of temporal and spatial contaminant trends.

It was recognized that a sedentary organism was needed to serve as a monitor of contaminants in the aquatic environment. An organism which could be utilized to pinpoint contaminant sources for further investigation. The clam, or mussel (Unionidae), is a filter feeder synthesizing dissolved and particulate material; sedentary; easily handled; ubiquitous; and provides sufficient tissue for an organic or metal analysis. Clams are not cannibalistic, as some aquatic insects and crayfish are (this could result with depletion of the project sample). They do not have an exoskeleton which may be lost(molted) and with it part of the contaminant burden. Clams are excellent for transplanting from place to place and caging, for locating on the sediments or suspended in the water column. Clams are found to reflect what is in the water as well as what is found in resident fish species (Curry, 1977/78). Clams can be used to pinpoint contaminant sources. The major species used in Ontario has been *Elliptio complanata*. Some work has been done with indigenous clams (Lampsilis, Anodonata sp.) depending on the geographical area.

Crayfish have been used in several situations, but tend to be cannibalistic, have a tendency to escape (from tanks or cages), and they molt between life stages (John Parks, personal communication). The molting makes them vulnerable to predation and disease, and reduces their contaminant body burden. These problems reduce their potential as a biomonitoring organism.

In the mid-1970's increasing levels of nitrogen and phosphorus created the proliferation of *Cladophora* in Ontario lakes. Surveys suggested that the geographical distribution and biomass availability of *Cladophora* might make it serve as a biomonitoring tool. Since 1980 it has been used as a heavy metal indicator, and more recently it has been developed as a potential biomonitor of organic contaminants (Michael Jackson, personal communication).

In the past 2 years, the Ministry of the Environment and Environment Canada have been involved with the evaluation of the leech as a biomonitoring tool. Leeches are easily collected, omnivorous, ubiquitous, easy to handle, transport, and cage. To date they have provided a better indication of the presence of chlorophenols than either clams or fish (Janice Metcalfe, Al Hayton, personal communications). Although additional work is required on the use of leeches, at this point they are favoured for chlorophenols (Metcalfe and Hayton, personal communications).

4.0 BIOMONITORS USED IN THE FRESHWATER AND MARINE ENVIRONMENTS FOR ORGANIC AND HEAVY METAL CONTAMINANTS

Tables 1 and 2 provide a summary of the literature on potential freshwater biomonitors, organisms used somewhere to date. Table 1 pertains to organic contaminants and Table 2 to metals. Table 5 gives some examples of organisms exposed to specific contaminants at stated concentrations and provides information on the resultant accumulations.

Since the freshwater literature is scarce, marine references have been included. It is recognized from the literature that direct extrapolation can not be made from one species to another, or contaminant to contaminant. Consequently it is not intended to imply that the freshwater and marine information can be interchanged. Marine references are intended for information purposes only. Appendices 2 and 3 contain similar information to Tables 1 and 2 but with respect to the marine environment.

4.1 Algae

Use of phytoplankton as a biomonitor may be restricted by the following factors:

- age of the cells;
- species differences in bioaccumulation ;
- water pH;
- the presence of dead specimens;
- the degree of chlorination of the contaminant;
- sensitivity to metals and some organics (toxicity);
- behaviour;
- morphology of the water body being examined;
- physical size of the algae;
- logistics of collecting samples of sufficient quantity for analyses.

Phytoplankton in bioaccumulation studies were used by: Cain et al 1980; Laube et al 1979; Wang et al 1982; Hart et al 1977; and Walsh et al 1977. Their experiences indicate diversity in responses from species to species and contaminant to contaminant. Age and growth rate of the cells influenced cadmium uptake by the colonial green alga *Scenedesmus obliquus*. Rapidly growing cultures accumulated less cadmium than did older cells at a stationary growth phase (Cain et al 1980).

In the laboratory *Anabaena, Ankistrodesmus braunii*, and river sediments were exposed to cadmium and copper over a 72 hour period (Laube et al 1979). *Anabaena* accumulated cadmium reaching equilibrium in 12-24 hours as determined by the ratio of heavy metal ion accumulated by alga to heavy metal ion accumulated by sediments (1.67 for *Anabaena* and 2.22 for *A. braunii*). Equilibrium was reached after 12 hours with copper, with the ratios *Anabaena* 0.65 and *A. braunii* 1.2. Algae accumulated cadmium more successfully than copper and competed effectively with the sediments for the two metals (Laube et al 1977). Laube et al (1977) believe algae can remobilize copper and cadmium from the sediments, so design of a biomonitoring project must take these potential sediment contaminants and contributions to the water column into account.

Hart et al (1977) found that pH affects the algal growth rate. Higher pH (eg. pH 8.0) increases the growth rate. Depending on the pH, *Chlorella pyrenoidosa*, could concentrate cadmium proportional to the initial water concentration. Hart et al (1977) found that the presence of manganese, iron or EDTA can block cadmium accumulation by blocking transport sites leaving no place in the phytoplankton cell for cadmium to accumulate. Water pH and the presence of other metals in the water body must be considered in interpreting the results of bioaccumulation studies using phytoplankton.

Wang et al (1982), found that *Chlorella fusca* accumulated three PCBs (2,4'-dichlorodiphenyl, 2,4,6,2'-tetrachlorobiphenyl and 2,4,6,2',4'-pentachlorobiphenyl) through adsorption onto the cell and absorption through the cell to the hydrophobic lipid part. Both live and dead cells accumulated PCBs in the same time with concentration factors of 5630, 5420 for living cells and 4760 and

5140 for dead cells in 24 hours. PCBs increased linearly with the concentration in water. Hart's et al (1977) work did not show cadmium to be accumulated in the dark or in dead cells. It appears that there may be a major difference here between the organic and metal contaminant's mechanism of uptake. Dead cells in a sample may give a false impression of organic contaminant levels if organics do in fact become adsorbed and are not actually biologically available.

The only other available literature dealing wit' algae and organics was work done by Walsh et al (1977). They examined marine unicellular algae *Dunaliella tertiolecta, Chlorococcum* sp., *Nitzschia* sp. and *Thalassiosira pseudonona*. These algae bioaccumulated chloronaphthalenes but the degree depended on the chlorine content of the contaminant. The concentration factor was only 140 (Walsh et al,1977).

The water solubility/bioaccumulation potential; uptake by dead organisms; and the importance of the chlorine content of an organic contaminant and its bioaccumulation, reduces the potential for the use of phytoplankton as a biomonitor for organics.

One of the major shortcomings in the use of phytoplankton is the ability to collect a pure and adequate sample. Since algal species have differing abilities to uptake metals and organics a collection of one species would be needed to provide a sample. Their small size makes sample collection an impractical proposition. The pH also affects algal growth and according to Cain et al (1980) would potentially distort the meaning of the contaminant results. Fast growth would give a picture of decreased concentrations of contaminants. Phytoplankton behaviour, ie. movement within the water column and distribution by water flow and currents reduce its eligibility as a biomonitor. Culturing and transporting to the field environment for a caging exercise can be done, but is not a practical solution when transportation long distances, and excessive handling may be required.

Studies of filamentous algae and contaminant bioaccumulation are more extensive than those of unicellular or colonial phytoplankton (Newman et al 1982; Bailey et al 1985; Foster 1982; Harding 1981; Whitton 1985; Jackson 1985).

The Ontario Ministry of the Environment has a database established of *Cladophora* biomonitoring results which can be related to spottail shiner (*Notropis hudsonius*) data. *Cladophora* reflect spottail shiner and clams contaminant levels (Jackson, 1985;Niagara River Toxics Committee).

Several studies indicate that some filamentous algae reflect the dissolved metals available in the water body (Bailey et al 1985, Foster 1982, and Harding 1981). Although filamentous algae can concentrate some contaminants to reflect environmental levels it is not true for all metals. Filamentous algae of thirty-six lakes in four geographic areas of Canada showed a 1000 to 10000 fold increase in concentrations of copper and cadmium in algae over that in water. The pattern indicated that the metal levels quantitatively reflect dissolved metals or water pH. No such pattern existed for other metals (Bailey et al,1985). Foster's (1982) study using *Spirogyra, Zygonium, Mougeotia,* and *Microspora* species indicated metal concentrations were several orders of magnitude higher than ambient levels. Iron levels plateaued at the water concentration of iron (1mg/ml) . Zinc (Zn) remained constant. The red alga *Lemanea* was transplanted and used in a mining area where zinc levels adjusted themselves to stabilize at concentrations similar to native filaments. Foster (1982) and Harding's (1981) work also suggest zinc regulation but high levels of calcium and/or magnesium resulted in decreased uptake of zinc in Harding's work (1981). Iron and zinc are not considered contaminants to be monitored using filamentous algae.

Newman et al (1982) found lead levels highest in filamentous algae after July and August. This coincides with the period of macrophyte die-off and the highest levels of lead found in macrophytes. Algal sampling taking place during this time period may distort the interpretation of the availability of lead in the system.

Phillips (1978) discusses macroalgae in the marine environment (*Fucus vesiculosus, F.serratus, F.spiralis, Laminaria digitata, Ascophyllum nodosum,* and *Ulva lactuca*) which are responsive to the soluble trace metal content of their environment rather than to organic or inorganic particulate matter. They reflect the soluble concentrations with a high degree of time integration. Phillips ( ) feels that macroalgae are best suited to looking at metals in solution, where binding occurs to alginates in the cell wall. Some pollutants inhibit growth, while in the case of manganese, iron and possibly zinc, the plant regulates them. In these particular cases macroalgae would not be used as a biomonitor.

As with the freshwater filamentaous algae, position on shoreline and water temperature are important. In the marine environment, salinity is a strong factor in controlling plant growth and determining the number of binding sites available to the contaminant.

Whitton (1985) suggests that macroalgae such as *Cladophora, Enteromorphe, Ceratophyllum* and *Vallisneria* (in England they may be considered a macroalgae) would be ideal biomonitoring organisms. *Vallisneria* sp. is for example found in abundance in Ontario's inland waters where *Cladophora* is not (due to differences in habitat preference ie. lentic areas of usually mud-type sediments, versus rock and heavy wave-action). Filamentous algae such as *Cladophora* on the other hand , could be used as a nonpoint source tool in areas such as the Great Lakes, and around specific outfalls where habitat is suitable. Its use would be restricted to that of seasonal integrator rather than one of greater duration since it lives and dies in a relatively short period as compared to clams or fish.

4.2 Zooplankton

Zooplankton has had limited research with respect to its use as a field biomonitor. Marshall et al (1983), in a Lake Michigan study, found that zinc could significantly reduce zooplankton populations at levels below the reported toxicity for zooplankton. Zinc can also suppress cadmium accumulation distorting results of any study where cadmium may also be present.

Havas' (1985) work with aluminum (Al) and *Daphnia magna* in soft water at various pHs indicated that the maximum aluminum toxicity and bioaccumulation arrived at, was pH greater or equal to 6.5, and a concentration of total aluminum (Al) of .32 mg/l. After 24 hours the bioconcentration ratio was 10,000 at pH 6.5, 4,000 at pH 5.0 and negligible at pH 4.5.

These studies indicate that zooplankton can be susceptible to metals at levels lower than previously determined, depending on water pH and hardness. Bioconcentration does occur and in a relatively short time (24 hours), but attention must be paid to other water quality factors in interpretation of results.

Evans et al (1983), proposed that *Mysis relicta* acts in remobilizing lead from the sediments to the water column. During their daily migration upwards in the water column lead is released as faecal material. The faecal material is ingested by other organisms and made available to them, and or settles back to the sediments and is ingested again by benthic organisms. *Mysis relicta* could be a useful remobilization organism, but would not be considered a useful biomonitoring organism for lead due to its rapid excretion.

The only information related to zooplankton and organics was a study by Larsson (1986) who used PCB contaminated sediments and several organisms as PCB accumulators. *Daphnia magna* did accumulate PCBs from the sediments following a seasonal pattern where levels decreased in the autumn, probably due to nothing more than new generations of daphnids entering the system, and thus greater partitioning of the available PCBs and rose again in the spring.

Zooplankton is not a feasible biomonitoring tool. Like phytoplankton, the life span, species composition and biomass are limiting factors in obtaining adequate analytical samples. Daily migrations through the water column complicate the contaminant source within the system, and they are too sensitive to some metals and pH changes. The literature lacks information on zooplankton use as a contaminant bioaccumulator but does provide considerable information on uses of zooplankton for acute toxicity work.

4.3 Macrophytes

The macrophytes, *Lobelia*, *Eriocaulon*, and *Potamogeton* , analyzed after radium dosing an experimental lake, responded to the maximum dose in 20 days reaching a maximum level of 44 and 52 Bq/g and 208 mBq/g respectively. *Lobelia* and *Eriocaulon* eventually levelled out to 11 and 15 mBq/g after 3 to 4 months, *Potamogeton* to a level four times higher (Hesslien et al, 1984). When compared to fish and crayfish, macrophytes appeared to have the least variation among samples although not necessarily species.

Macrophytes, *Potamogeton foliosus* and *Najas quadelupensis* (Knowlton et al, 1983), *Brasenica*sp., *Utricularia* sp. *Caloma* sp. and *Myriophyllum* (Newman et al,1982) examined from areas of sediment lead (Pb) loads indicated lead uptake by roots but no translocation through the plant. Lead concentrations were highest in July-August but were associated with sediment levels rather than water (Newman et al,1982). Franzin et al (1980), also examined macrophytes (*Sparangium, Utricularia vulgaris, Myriophyllum exalbescens, Nuphar variegatum, and Calla palustris)* and metal uptake near a base metal smelter. Again they found metals to be concentrated in the roots of the plants. Those with large fleshy roots accumulated more metal than plants with small fine root systems. The only relationship between metal emissions from the smelter and metal concentrations in the plant was related to the calcium content of the water.

Breteler et al (1982) investigated uptake of metals from a sewage sludge fertilizer used in an experimental marsh. As the sediment mercury rose, the concentration in roots rose. Leaves took some mercury from the water but other plant parts did not change. When the organic content of the sediment decreased the concentrations of mercury in plants increased. Macrophytes appear to be most affected by metal concentrations in sediments rather than the surrounding water body. The form of metal biologically available is influenced by the organic content of the sediments.

The only reference in the literature to macrophytes and organic contaminants was to Mozek Jr. et al (1981). They used the saltmarsh cordgrass (*Spartina alterniflora*) to examine the uptake of PCBs. The lesser chlorinated PCBs were accumulated. As with the marine phytoplankton study and chloronaphthalene uptake, the degree of chlorination plays an important role in plant uptake. They believe this to be a pathway for movement of some PCB congeners from the sediments.

Consideration for macrophyte use as biomonitors must be given to: the contaminant of interest ie. freshwater data of uptake and organics is limited; the sediment load of contaminants versus the contaminant of interest; the sediment organic content; the surface area/volume relationship in selecting species for use; use of the roots as the analytical sample; the time in the growing season the plants are to be sampled; and, areas of natural occurrence.

2.? Aquatic Insects

Nehring's (1976) laboratory and field caging studies using mayfly naiads (*Ephemerella grandis*) generated concentration factors for heavy metals. The field study occurred in a stream naturally polluted with zinc. Insects were collected at 49 hours post initial exposure and 24 hours thereafter. Laboratory and field study results were similar. Mayflies collected the heavy metal in relative proportion to the water metal concentration.

Colborn's (1982) river study of caged mayflies (*Drunella grandis*) and caddisflies also showed that mayflies are capable of concentrating metals (in this case cadmium), from surrounding waters. Cadmium and molybdenum were low in water analyses. Exposure periods were relatively short, 24, 48, and 72 hours as in Nehring's (1976) work. Cadmium equilibration occurred in 72 hours (Colborn, 1972). Caddisflies also concentrated cadmium but not to the level of the mayflies. The advantages of using mayflies are: they are more metals tolerant than are fish; they concentrate metals in relative proportion to concentrations in water; they also concentrate metals by a predictable, reproducible factor.

Dressing et al (1982), investigated the effect of a synthetic chelator (nitrilotriacetic acid (NTA)) on cadmium accumulation by the caddisfly, *Hydropsyche* sp. Equilibration occurred between the animals and the synthetic metal solution within 3-5 days. They found both free cadmium and cadmium bound to NTA to be accumulated by *Hydropsyche* sp. Other work has indicated that cadmiun complexing with other organic ligands reduces uptake by *Chironomus* This area requires further study but feeding behaviour may explain the differences in uptake. *Hydropsyche* sp. use as a biomonitor may be restricted to its predaceous behaviour requiring special caging techniques.

Dressing et al (1982) and Colborn (1982) looked at dead and living insect concentrations of cadmium. Dead insects did not accumulate to levels as high as living ones, indicating that cadmium uptake is an active sorptive process likely through the gill membrane, and may be an important factor in cadmium accumulation (Dressing et al, 1982). Cadmium in dead organisms may be an adsorptive process and must be considered in the result interpretation.

Rossaro's et al (1986) bioaccumulation studies with larvae and adults of *Chironomus riparius*(Meigen) exposed to mercury indicated a mechanism of elimination of mercury by the adult. The bioconcentration factor in larvae with respect to water was 12600 while that of exuviae was 12470. Adult levels were only 29% of the larvae levels. As with crayfish, the metal can be concentrated in the exoskeleton and lost during molt.

Consideration must be given to: the life stage chosen for use; sediment type; and complexing potential of contaminants with organic ligands, for aquatic insects to be used as biomonitors.

Mayflies are potentially the best insects for biomonitoring. Accumulation and equilibration for some metals has been short-term (up to 5 days). Immature stages of the insects are best suited to biomonitoring since they are relatively sedentary. Adults have been shown to have lost metal body burdens as a result of molt, therefore timing of the biomonitoring exercise is restricted to the intermolt phase. Indigenous animals, particularly in river situations, are subject to drift. They would not be useful for site-specific monitoring. Small size increases the need for large numbers to provide an adequate analytical sample. From a practical view point, the biomass required to provide a representative analytical sample, and problems related to predation (as with *Hydropsyche* sp.), and life cycle change/molt, reduce their potential as biomonitoring organisms.

4.5 Crustaceans

Landrum et al (1983), studied the influence of anthracene uptake, depuration, and biotransformation by the amphipod *Hyalella azteca*, with and without sediments. The mean water rate constant for uptake from water was the same with or without sediments , 255 +/- 76 ml (g animal wet weight) times the hour, while the rate constant for uptake of the sediment associated anthracene was 19 +/- 5 g dry sediment (for an organic sediment). The depuration of anthracene increased three times when there were sediments. The sediment associated anthracene contributed 77% to the steady state body burden. Bioconcentration factors from body to water concentration are often over-estimates because sediments are not taken into account.

Lewis et al (1986) investigated the freshwater isopod *Asellus communis*,(a hardy detritivore, living associated with sediments), for its ability to accumulate zinc and lead. Zinc was regulated by the animal. Lead was affected by pH with significant accumulations at pH 4.5 and 5.5. At pH 5.5 the rate of lead uptake was greater from sediments than water. Lead associates itself with amorphous iron oxides which undergo dissociation at low pH, thus making lead more available for uptake by *Asellus*. *Asellus* is not a good biomonitor for zinc since it regulates zinc and would have to be used for lead at certain pHs to ensure confidence in result interpretation.

Anderson et al (1978), collected *Orconectes virilis* from three sites to look at patterns of trace metal accumulations. Within sites there was no significant difference in metal concentrations between sexes; nor were there any consistent trends between size classes for copper, cadmium, lead or zinc. Anderson (1978), also found that metals not regulated by the animal were found at environmental levels, while copper and zinc (regulated) were higher in tissues and similar at all sites. Zinc is regulated by the hepatopancreas while copper is regulated by the haemocyanin. Highest levels for copper were found in the gills. The lowest concentrations of metals were detected in the tail muscle. Lead was found in the exoskeleton.

Ober et al (1987) investigated metals in 7 molluscs, 3 crustaceans and 2 other shellfish. Of copper, zinc, cadmium, lead, mercury, nickel, antimony, selenium, iron, and chromium, the zinc and iron were highest in crustaceans, while copper and antimony accumulated similarly between molluscs and crustaceans. The remainder were highest in molluscs.

Knowlton et al (1983), examined the uptake of lead from contaminated sediments by aquatic macrophytes and crayfish. Some crayfish were exposed to sediments, others not. Smaller crayfish accumulated more lead than did larger crayfish, and those exposed to contaminated sediments accumulated four times the lead the other group did. Anderson et al (1978) had not found any trends in lead uptake with sizes. Lead is concentrated in the exoskeleton and is lost during molt. Knowlton et al (1983) found that the internal visceral lead was never significantly different between the controls or the others even

though the crayfish often eat the shed exoskeletons. It appears that lead is quickly moved to the exoskeleton. Therefore the size of the crayfish and frequency of the molt may play a significant role in the amount of lead detected through a biomonitoring program. Crayfish caged in the Wabigoon-English system of Northwestern Ontario (Canada/Ontario Technical Report) in 1978 and 1979 were fed mercury contaminated fish exposed to the mercury contaminated system. The crayfish became sensitive to mercury during molt and lost some of their bioaccumulated mercury (personal communications). Parks et al (1980 report on the Wabigoon-English System) collected crayfish (*Orconectes virilis*) from the system from 1970 to 1979. As the system's mercury levels decreased so did those in crayfish. In the same system crayfish were compared to young pike, adult pike, and yellow perch. The crayfish and perch were both good indicators of mercury contamination.

Some of the practical problems associated with crayfish caging in the Wabigoon-English system were: crayfish cages tended to accumulate coverings of suspended materials restricting water flow through the cages; crayfish became cannibalistic reducing the available sample size; and, molting distorted accumulation results, but made the organisms extremely sensitive to disease and fungal infections.

Rincon et al (1987), tried to determine a relationship between size and mercury concentration. The theory has been proposed that in a highly contaminated system there is a length/body burden relationship for mercury. However, Rincon et al's (1987) field study indicated a statistically significant relationship between mercury concentration and size but the system was not considered contaminated.

Heit et al (1977) exposed two freshwater crayfish species to mercury in the laboratory. The crayfish's ability to accumulate inorganic mercury depended on the crayfish species, size, sex, and external temperature. The form of mercury (organic/inorganic) may explain the differences found in size and sex with respect to uptake. There were no statistical differences in the red crayfish (*Procambarus clarkii*) in the mercury content between the sexes. It appears that these factors in conjunction with the loss of mercury during molt, the caging , and behavioural problems reduce the crayfish's utility as a mercury biomonitor.

Bioaccumulation and long-term 226 Radium (Ra) concentrations were measured in natural components of the biota of a Canadian Shield Lake. *Orconectes virilis* concentrations rose to 370 mBq/g wet weight over a one month period remaining so for at least three months (Hesslein et al, 1984). Macrophytes were another component exposed. Concentration variations between crayfish were greater than those between macrophytes. Crayfish accumulated 226 radium from food and water. Macrophytes accumulate contaminants through sediments only.

Orconectes virilis and *Cambarus bartoni* were used as intermoult adults to demonstrate the accumulation of copper, cadmium, and nickel in crayfish from copper-smelters in Sudbury, Ontario (Begatto et al ,1987). No significant differences in metal concentrations between sexes were noted. This agrees with Rincon et al (1987). Differences between lakes and distance from the smelter were determined. As in other studies, the highest concentrations of metals were detected in the hepatopancreas. The order of concentration was: hepatopancreas, exoskeleton, abdominal muscle, digestive gland, gut , viscera (gills, reproductive organs). Crayfish can store copper , which was found at high levels. Cadmium which follows the same pathway as copper was found stored in the protein metallothionein. Cadmium and nickel accumulated in the exoskeleton. As with mercury and lead these metals would be lost during molt.

Orconectes virilis becomes increasingly sensitive to cadmium with time, causing cessation of the molting process. In bioaccumulation studies the whole body demonstrated a linear relationship of cadmium concentration to exposure concentration. The gill and antennal glands demonstrated a similar pattern. Overall the pattern of distribution was: highest concentrations in gill > hepatopancreas > antennal gland > carapace and abdominal muscle (Mirenda, 1986). The distribution pattern varied slightly from Begatto et al's work (1987).

Freshwater data for crayfish and organics accumulation is scarce. Kanazawa (1978) exposed Procambarus clarkii and several fish species to diazinon. He indicates that fish were better accumulators than were the crayfish but offers no explanation. The marine literature is more extensive on this subject.

Breteler (1981), used fiddler crabs (*U.pugnax*), mussels and marshgrasses in an experimental marsh with sediments and mercury contaminated fertilizer. As the organic content of the sediments decreased, levels in the organisms increased but additions of mercury to the sediments without a change in organic content , did not cause a mercury concentration change in the organisms. Fiddler crabs accumulated less than mussels at all times, although both are detritivores. Assuming mercury is accumulated via water and food, another mechanism regulating the mercury uptake by the crab must exist (Breteler, et al,1981).

Uthe et al (1986), studied polynuclear aromatic hydrocarbon (PAHs) contaminants in the American lobster (*Homarus americanus*) from a coal-coking plant. Lobsters were collected a year after each plant closed. They rapidly accumulated PAHs but when left 12 months in laboratory water lost only high water soluble PAHs. Distribution is mainly centred in the hepatopancreas eg. 2300 ng/g wet weight in the digestive gland versus 281 ng/g wet weight in the tail.

Radiolabelled phenanthrene and octachlorostyrene were given intragastrically to spiny lobsters (*Panulirus argus*). Octachlorostyrene was found to be highest in the hepatopancreas, while the gills and heart had the highest levels of phenanthrene (Solbakken et al,1986). Concentrations of each were equal in the muscle and green gland. Crustaceans metabolize phenanthrene and is rapidly eliminated from the hepatopancreas. Two weeks after dosing half of the radioactivity still remained in most tissues including the muscle.

The crayfish *Astacus leptodactylus* was injected with phenols to determine the distribution and elimination process (R.Nagel et al 1981). A two compartment model describes the levels of phenols (phenol; 3-nitrophenol; 3,5 diethylphenol ; and 4-aminophenol) in the crayfish. The major route of excretion for organics in crayfish is via the gills according to Nagel et al (1981). Zabel et al (1971) showed that crayfish only eliminated via the antennal gland. Further study is needed to resolve these discrepancies.

Leonhard (1979) has had considerable experience using crayfish (*Orconectes virilis*) in toxicity and bioaccumulation studies. She believes crayfish are useful biomonitoring tools for some of the following reasons:

- they are widely distributed in North America;
- omnivorous and key energy transformers between various trophic levels;
- they are large enough to provide sufficient tissue for analysis to give ug/l residue levels;
- any tissue can be used(gills, liver, stomach, intestine, gonad, heart, tailmuscle, haemolymph and carapace);
- exposure to certain contaminants (eg. cadmium) will stop life changes ie. molting.

The literature indicates tissue preferences by each metal which eliminate Leonhard's suggestion that any tissue could be used for analyses. The organics studied do appear to be preferentially located in the hepatopancreas.

The literature has indicated the crayfish's ability to bioaccumulate. However, the majority of the data has been related to metals. Copper, and zinc are regulated by the crayfish therefore do not reflect the environmental levels of these two metals. Cadmium affects the organism by interrupting the molting process; mercury, lead, and nickel accumulate in the exoskeleton which is lost during molt. Molt restricts the time of use of the crayfish. An advantage of crayfish over other organisms is that sex differences have no significant impact on bioaccumulation potential. The other advantage is that the hepatopancreas appears to be the organ which accumulates most organics. However metals appear to accumulate in specific tissues depending on the metal.

4.5 Worms

Oligochaete worms *Limnodrilus hoffmeisteii* and *Tubifex tubifex* were exposed in the laboratory to "naturally" contaminated Lake Ontario sediments (Oliver ,1984). Worms were recovered at 33, 52 and 110 days and allowed to depurate for 48 hours. Uptake was proportional to sediment chemical concentrations although small worms tend to accumulated more than large worms.

Chapman (1985) investigated the contribution of gut content contaminant burden with respect to the total contaminant load (metals) using *Limnodrilus hoffmeisterii* and *Tubifex tubifex*. 3ut metal contents comprised the higher percent of the total metal load. A depuration period is necessary to remove the gut load to determine the metal actually biologically available in the organism.

Elder et al (1979), exposed the marine polychaete *Nereis diversicolor* to PCB spiked and unspiked sediments. After 40-60 days the worms reached equilibrium. Uptake from sediments was dose-dependent as with the freshwater *L.hoffmeisteii* and *T.tubifex*. A depuration period of 60 days brought their levels back to that of worms in unspiked samples. Worms with higher levels had higher initial loss rates (Fowler et al, 1978). They feel these worms may cause remobilization of PCB contaminated sediments since they uptake most of the PCBs from the sediments.

The marine deposit feeding polychaete *Nereis nereis* was exposed to cadmium contaminated sediments. As in Oliver's work (1984), Ray et al (1980) found that smaller worms had higher uptake rates than larger worms. After 24 days small (1-2 grams 11/2 - 2 years) worms had a concentration of 28-54% higher than large ones (5-7 grams 3-4 years old). Water cadmium was related to sediment cadmium and cadmium in worms was taken up through water. In a case like this, worms can not eliminate wastes, therefore physiological processes are impaired with time. In another piece of work with *Nereis nereis* , Ray et al (1981) concluded that *N.nereis* might be useful in testing for cadmium and lead because they can accumulate the contaminants in proportion to the water concentrations. However, the possibility of contribution from sediments would need to be explored and removed from result interpretation.

Rubinstein et al (1983) also suggested *N.nereis* to be a useful biomonitoring tool. *N.nereis* was exposed for 100 days to dredged sediments containing PCBs, mercury and cadmium. Only PCBs accumulated above background concentrations suggesting the metals were bound to the sediments and not biologically available. *Nereis nereis* accumulates contaminants via interstitial waters, ingestion, and absorption from sediments.

The effects of silver on respiration and ionic and water balance of *Nephtes virens* was studied by Pereira et al (1981). In 24 hours those exposed to 0.5 ppm accumulated 18.8 +/- 8.6 ppm; 0.8 ppm accumulated 74.6 +/-46; 1.0 ppm accumulated 209 +/- 48.5 ppm. Silver continued to increase for 72 hours at 0.05 ppm. Overall, *N.virens* did not accumulate according to size but to water concentration of silver.

The freshwater literature is not extensive with respect to the use of aquatic worms as bioaccumulators. Worms are small requiring a substantial number to provide an adequate analytical sample, but they are sedentary and easy to handle. Their association with sediments may restrict their use as biomonitors to areas related to sediment impact by contaminant sources. The worms have been shown to reach steady state. Because internal or gut contaminant content is the highest percent of the total contaminant metal load it is essential to depurate prior to analyses to determine the amount of contaminant biologically available in worm tissues.

4.7 Leeches

Leeches are a relatively recent addition to the field of biomonitoring. Leeches (family Hirudinea) caged at a forest industry outfall for 1 week had 100% survival. Chlorophenols were not detected in water but were detected in the leeches. The bioconcentration factor was 40-100 after 24 hours (Jacobs et al,1985). After 1 week depuration there was no sign of release of chlorophenols. Two factors could increase the bioconcentration and should be carefully observed in testing with leeches: 1) temperature, and 2) body size. These are two variables which have shown to influence accumulation by other organisms.

Several organisms from Canagagigue Creek were examined for chlorophenols (Carey et al ,1983). Fish rapidly accumulated chlorophenols but eliminated them as quickly (10 hours). Of the benthic species, leeches had the highest levels of chlorophenols.

Metcalfe et al ( ), collected water and leeches at five stations in New Brunswick, levels in water ranged from non-detectable (ND) to 0.035 ug/l. Twelve chlorophenol isomers were detected in leeches. The four species of leech collected were : *Glossiphonia complanata* (accumulated the lowest levels , 60 ug/l or less, even at the most contaminated site); *Helobdella stagnalis* (higher levels of the more highly chlorinated phenols); *Erpobdella punctata* and *Dina parva* (higher levels of the lower chlorinated phenols). Although the leeches were excellent at detecting chlorophenols, they did not accumulate any of the organochlorines detected in the water samples. Leeches appear to accumulate water soluble contaminants but do not accumulate those that are lipophilic.

Metcalfe et al (1984), analyzed fish, crayfish, bullfrog tadpoles and leeches from Canagagigue Creek in Ontario. Leeches accumulated 40,000 times to 140,000 times the average water concentrations of 2,4-DCP and 2,4,5-TCP respectively. *Dina dubia* accumulated the highest levels on all occassions except 2,6-DCP in June and PCP in November. *Glossiphonia complanata* accumulated the lowest levels. The levels were one to two orders of magnitude higher than levels found in 13 other species of benthic invertebrates as well as fish and tadpoles. Because leeches are fairly primitive animals, they may not be capable of metabolizing and/or excreting chlorophenols. *D.dubia* did not eliminate any chlorophenols in two weeks of depuration.

Jacob et al (1985), consider leeches to be excellent candidates for biomonitoring. The following characteristics of leeches emphasize the basis for this opinion:

- resistant to toxic compounds
- naturally abundant
- reasonable size
- long survival in the lab
- tolerance for brackish waters
- starvation resistant
- bioconcentration capability
- correlation established between their body pollutant content and concentration of pollutant in the surrounding water.

The literature available at this time for leech biomonitoring studies deals only with organic trace contaminants ie. chlorophenols. The leech has been shown to bioaccumulate them quickly and to levels much higher than water, suggesting they are the best organism at present for biomonitoring of chlorophenols. As indicated by Jacobs et al (1985) the leech does meet most of the criteria suggested by Phillips (1973), and additional work is currently underway to evaluate and/or confirm past study results.

4.8 Molluscs

Gastropods

Newman et al (1982), investigated several components of a freshwater ecosystem with elevated lead levels in surficial sediments. The gastropods *Physa integra*, *Pseudosuccinic columella*, *Helisoma trivolis* and *Idiopoma malleata* had the highest levels of lead. However, these seemed to correlate with dissolved lead in the water rather than those in the sediments. The lead in *P. integra* related to the levels in the macrophyte *Calombe* sp., which *P. integra* feeds on.

Everard al (1984) looked at cycling of lead from detritus through snails, snail-predators and back to the sediments . The highest lead levels concentrated in the digestive gland, feet and shells of *Valvata piscinalis* and *Lymnaea peregra* Lead was lost when the organisms were exposed to a clean environment. Lead was incorporated into the shell, lost by the foot, and lost even quicker by the digestive gland. The gut wall and digestive gland are able to regulate lead in these organisms.

Newman et al (1983), studied two gastropods *Physa integra* and *Campeloma decisum* to determine if size had any impact on accumulation of lead. Lead concentration was independent of size in *P. integra*, but smaller snails had higher lead concentrations than larger snails of *C. decisum*. *P. integra* eliminated lead rapidly over the first four days of exposure but lost it much slower thereafter. *C. decisum* showed no significant decrease in body lead concentrations. Newman et al (1983), suggest that there are two things

controlling metal content in snails: an active mechanism linked directly to metabolism, and, the surface volume ratio of the animal. Size range examined was:

C.decisum 0.0046-0.2775 g dry weight and 5-33 mm shell length
P.integra 0.0007-0.0070 g dry weight and 3.6-8.1 mm shell length

Physa integra 's immature stage is very sensitive to cadmium, three times more so than the mature snail (Weir et al,1976). Cadmium was rapidly acquired and concentrated reducing reproduction. Weir et al (1976), suggests that cadmium interrupts cellular metabolism by bonding to sulfhydryl groups of enzymes at sites that must be occupied by other anions for proper function.

Isensee's (1978), bioaccumulation laboratory study using 5 species, algae (*Oedogonium cardiacum)*, daphnids (*Daphnia magna*), snails (*Physa*sp.), mosquito fish (*Gambusia affinis*), and channel catfish (*Ictalurus punctatus*), and the contaminant 2,3,7,8-tetrachlorodibenzo-para-dioxin included an exposure period of 32 days. The concentration in the organisms ranged from 2 to 7000 times the water concentration, and was directly related to the water concentration. Equilibrium was reached in 7-15 days.

Gastropods are an ideal size to work with but have certain water quality requirements which are not likely to be found at all industrial discharge sites, (a plentiful supply of oxygen, good alkalinity 20-180 ppm, and pH higher than 5.5 (Harman, 1974)). Although they do accumulate metals, some species are sensitive to cadmium, and can regulate some metals through some mechanism in the gut walls and digestive gland. The literature indicates they tend to accumulate from the water column or from macrophytes they feed on, and not from sediments. This indicates some species could be useful in a caging experiment without sediment contact, as long as the animals were not feeding, and the objective of the project was not to look at sediment contributions. Differences in species, and size versus accumulation, is a consideration in comparing gastropod accumulation results from site to site.

Bivalves

Molluscs are used as biomonitoring organisms around the world. The "International Mussel Watch" program is extensively developed in the United States, with programs using molluscs in South Africa, Scotland, and the Netherlands. They have been used in Spain, Japan, Finland, Australia, Chile and Canada . Literature on bivalve molluscs as biomonitoring organisms, and particularly marine bivalves is extensive, although the bulk of the literature relates to metals rather than to organic contaminants. Because the information is extensive but not clear, Phillips' ( ) comment should be reiterated here;

"different species exhibit widely divergent rates of uptake and excretion for any one contaminant, and this variation depends better on taxonomy; thus, closely related species may not be assumed to exhibit similar pollutant kinetics".

Bearing this in mind, freshwater and marine information is presented for consideration.

Dermott et al (unpublished) looked at metal concentrations in the annual shell layers of the bivalve *Elliptio complanata* Zinc has a preference for soft tissues while lead has an affinity for the shell. Zinc accumulated in the whole body over a seven day period, with shell levels 3.7 mg/kg, while soft tissues were 62 times greater. Copper and nickel were located equally in shell and soft tissues. As with organisms previously mentioned, copper and zinc do not necessarily reflect the environmental levels but are regulated by the animal.

Imlay (1982), feels shells are useful as indicators of contamination. Mussels have distinct annual rings and distinct stress rings indicating the mussel has stopped growing. Differences in the metal levels in shells depends on species, age , and layer differences , however sex does not seem to make a difference.
Metals can go to a couple of places within the shell structure. Contaminants can be tied up in the periphyton on the shell. Inorganic lead for example is not deposited in the prismatic layer, the organic form goes to the outer periostracum (Dermott et al,unpublished). High iron levels can bind the inorganic metal forms onto hydrous iron oxides which are then biologically unavailable to the clam.

Manly et al (1977), examined metal (Zn, Ni, Pb, Cd, Cu, Hg) occurrence in a population of *Anodonta anatina*(L.). Immature stages were used and differences found in levels at the same site. The distribution in the organisms are: zinc and copper to the mantle, ctenidia and kidneys; nickel to the kidneys, mantle and ctenidia; lead to the digestive gland and gonad; mercury to the kidneys, then evenly distributed. If the metal concentrations are high there is a metal concentration/body weight correlation. The polyvalent ions Zn^{++}, Cu^{++} and Hg^{++} became concentrated on mucous sheets. The mucous sheets are extracellular products so the ions are not assimilated within the tissues but are absorbed to a surface layer.

Adams et al (1981) transplanted the three-ridge clam (*Amblema perplicata*) to the area of an electroplating industry. The study was aborted due to heavy flooding but, clams showed uptake of cadmium and zinc in 7 days. The highest zinc level was in the gill, and cadmium in the digestive gland. The gill acts as an adsorption/absorption mechanism for metals from food and particulate matter. The digestive gland is also an adsorption/absorption mechanism. Small particles are taken into the gland by phagocytosis or pinocytosis. Cadmium is then mediated by a carrier system and binds to calcium or manganese granules with subsequent storage in the digestive gland.

Anderson's ( ) study included six indigenous clam species from an agricultural and urbanized area. The metals accumulated within the shell and body in the following order - Cd < Cu < Zn < Pb and Cd, Cu, Pb. The body generally mirrored concentrations in the sediments, those in the shell were lower than sediments. The highest concentrations were found in the gills. Copper, cadmium, and lead levels were at or below those of the sediments.

The Asiatic clam (*Corbicula flumined*) was used in a four week lab study to determine their heavy metal indicator potential (Graney,Jr. et al,1983). They were exposed to the following:

cadmium	0, 0.023, 0.055 mgL-1 as CaCl2
copper	0, 0.016, 0.057 mgL-1 as CuSO4
zinc	0, 0.022, 0.043, 0.84 mgL-1 as ZnSO4

Copper showed the greatest amount of tissue uptake with a bioconcentration factor of 22,571 when exposed to 0.016 mgL-1; cadmium 3770 exposed to 0.023 mgL-1; and zinc 358 exposed to 0.433 mgL-1. Steady state for cadmium was reached at 0.055 mgL-1 while the accumulation patterns were similar at all concentrations. Copper had the same patterns of accumulation at all concentrations but there was no steady state reached at the end of the four weeks. As with copper, zinc was influenced by the length and concentration of exposure. There was no steady state reached for zinc at the end of 28 days. There was a linear relationship between zinc concentrations in water and accumulation. Zinc is regulated by the organism (Graney,Jr.et al,1983) and is therefore not a metal to be monitored by these organisms.

Czanezki (1987), transplanted pocketbook mussels (*Lampsilis ventricosa*) from an unpolluted site to a polluted one (one affected by heavy metals) in the same drainage basin. They were removed after exposures of 2, 4, 8 and 12 weeks, and depurated for 3 days. Lead and cadmium showed temporal and spatial trends, lead increasing by a factor of 175 and cadmium 35 over background levels. Mussels did not reach equilibrium at 12 weeks because the 74.2ug/g level did not approach the 386 ug/g for endemic mussels.

Imlay (1982) believes *Margaritifera margaritifera* and *Elliptio complanata*, are good candidates for monitoring because of their wide distribution. *Anodonta anatina*, according to Imlay (1982), is a good indicator of heavy metal pollution, concentrations increasing with environmental levels. *M.margaritifera* however are not as long-lived. He has found metals in the shells of these animals at levels several times those in the soft parts eg. cadmium 100 times the concentration in the soft parts, copper six times the concentration, lead 450 times the concentration, and manganese one times the concentration. He found copper to be 24 times more concentrated in the shells than in fish.

Hemelraad et al (1986) believes that *A. cygnea* is of limited value as a cadmium biomonitor particularly at high environmental levels. At certain levels of cadmium, the uptake is linear to 20 weeks. If the cadmium level is higher, eg. 25 ppb, a biphasic accumulation occurs where uptake is a relatively slow linear process for four weeks then

seems to stop for two weeks, then increases rapidly to saturation at 10 weeks with no further change. The gill concentration is representative of whole [illegible] concentrations during the biphasic accumulation. This indicates an example of ver[illegible]usely related animals behaving differently. Hemelraad also did additional kinetic studies comparing *Anodonta cygnea, A.anatina*, and *Unio pictorum*. His data confirms that cadmium accumulates in the whole animal as well as in separate organs for the three animals. Whole animal (soft body) burdens of cadmium were similar but individual organs varied according to species. Sizes of organs as with sizes of animals vary. Differences may also result from behavioural responses (Hemelraad et al,1986). *A.cygnea* is heavily pigmented often related to tolerance to anoxia. This may in turn promote uptake when other species can not tolerate low oxygen levels and stop siphoning. The other belief is that there may be calcium granules present in the mussel which are able to detoxify the cadmium and therefore make it unavailable in the form being analyzed for.

Dreissena polymorpha was taken from a clean area and caged for 40-60 days at 1-2 metres below the water surface. Cadmium uptake was related to the last three weeks of exposure while copper was related to the last week. The levels of cadmium are not known, but given Hemelraad et al's (1986) biphasic accumulation theory, this exposure and accumulation agree.

Smith et al (1975), investigated uptake of mercury of three species of mussel (*Anodonta grandis, Lampsilis radiata*, and *Lasmigona complanata*) from water and sediments. The three mercury compounds were methylmercuric chloride, phenylmercuric acetate, and mercuric chloride. There was a significant difference in uptake by the three species, with *A.grandis* accumulating the least amount. The rate of uptake increased with additional mercury concentration in the water. Temperature had no impact on the levels. A rapid loss of mercury occurred the first two days of depuration, followed by little to no release. Smith and Green (1975) concluded that water had to be very contaminated with mercury before levels became elevated in clams.

Metcalfe et al(1987), analyzed *Elliptio complanata* from a gold mining area and found high mercury and arsenic levels in soft tissues. They were taken from a very highly contaminated lake and found to be much smaller than others of the same age elsewhere. A high correlation of weight and age was determined, indicating age is important in

influencing bioaccumulation. Metcalfe et al(1987) consider *E. complanata* to be a poor regulator of mercury in that soft tissue concentrations increased almost exponentially with increasing body weight and age. This work concurs with the results of Smith and Green (1975) in that a system must be highly contaminated to achieve elevated mercury levels in bivalves.

Foster et al (1978) transplanted and caged mussels (*Quadrula quadrula*) downstream of a copper electroplating industry. The exposure periods were 14, 30 and 45 days. Those closest to the outfall accumulated 20.64 ug Cu g-1 in 14 days, ten times the control mussel levels. Mussel concentrations decreased with distance downstream. Transplanted four year old mussels exposed for 45 days showed copper levels to be inversely related to body weight (small mussels accumulated large amounts).

Holwerda et al (1986), collected *Anodonta anatina* and exposed them to 0.125 uM DBTC (equal to 15 ppb tin) for 7 months, then to bis(tri-n-butyltin) oxide at 5ug Sn/L. Clams did not survive more than six weeks.The highest concentration of tin was found in the kidney although it was much lower than cadmium found in the gills. The low concentration factor of tin found in the kidney indicates that the organotin compound is eliminated at a faster rate than inorganic cadmium (Holwerda et al,1986).

Harrison et al (1972) exposed *Anodonta nuttalliana* Lea to radionuclides (46Sc, 51Cr, 54Mn, 59Fe, 60Co, 65Zn, 157Eu, 182Ta, 203Hg, and 210Pb). All were found in internal tissues and organs indicating a transfer across the gut and/or exterior surface and circulation by the body fluid. The valence state determined the location of the radionuclide. High concentrations found in calcareous tissue were in a divalent state in soft tissues. Manganese, cobalt, zinc, and lead were found in the highest percentage in calcareous tissues while scandium, chromium, iron, europium, tantalum and mercury were found in higher percentages in the digestive organ.

Anodonta cataracta(7.0 cm long) was exposed to fenitrothion in the laboratory (McLeese et al,1979). The half life for fenitrothion is 0.3 to 8 days. Mussels were sampled at 0, 1 or 2, 4, 7, and 14 days and allowed to depurate for 1, 4, 7, 21 and 28 days. Concentrations of fenitrothion in individual clams was variable and excreted quickly.

Maki et al ( ), exposed 8 to 10 cm. long *Anodonta* sp. to 3-trifluoromethyl-4-nitrophenol (TFM) over a 24 hour period. Samples were collected at 1, 2, 5, 10, 14 and 24 hours. All animals concentrated TFM 3 to 4 times over 24 hours with significant individual variation, likely a result of behavioural differences. *Anodonta* eliminated TFM in 24 hours after exposure. exhibiting a variable rate of elimination. The half-life of TFM in foot, gill and viscera was 20.4, 20.2 and 20.1 hours respectively.

Both of these latter studies indicate significant individual variability in contaminant accumulation and elimination of organics. This may be a characteristic of *Anodonta* sp. or the age of the organisms used. Variability was reduced in using *E.complanata* by restricting the sample to a consistent size 6.2-7.2 centimetres in length (Curry, 1977/78).

An organochlorine pesticide monitoring program in the Mississippi River system involving 7 species of freshwater bivalve (*Amblema costata, Corbicula manilensis, Elliptio crassidens, Lampsilis anadontoides, L.claibornesis, Megalonaias gigantea, Plectomerus dombeyanus*, indicated *C.manilensis* to be the best for concentrating and eliminating pesticides (Leard et al, 1980).

Tatem (1986) exposed *Corbicula fluminea* to three concentrations of contaminated sediments for 48 days. Significant quantities of PCBs were accumulated but relatively little lead and no cadmium.

Salanki et al (1978) exposed *Anodonta cygnea* L. to lindane, phosphamidon, phorate and trichlorfon. A reduction in their active periods was evident in several days.

Bivalves exposed to PCBs in sediments accumulated PCBs:
C.virginica 81+/-32 ng/g tissue
M.arenaria 149+/-67 ng/g
M.mercenaria 131+/-27 ng/g

Sediment levels were 3.4-2035 ng/g (Stainken et al,1979). Uptake may be selective because the lower chlorinated isomers tended to accumulate in tissue more frequently than higher chlorinated isomers. This same occurrence was found in the marine phytoplankton and macrophytes.

Corbicula japonica was used to study the uptake of 1,3,5-trichloro-2-(4-nitrophenoxy) benzene (CNP) (Okyama et al,1986). The bioconcentration factor was 4000 in shellfish with a half life of 10.4 days. During the decreese in CNP concentration a linear relationship existed between log of concentration and time. However after 20 weeks this relationship no longer existed, indicating CNP came from sediments.

Crassostrea virginica and *Rangia cuneata* were collected from St. Louis Bay, Mississippi. Arsenic in *C.virginica* was twice that of arsenic in *R.cuneata,* selenium was two times higher in *R.cuneata* (Lytle et al,1982). There was a negative correlation of selenium and iron with weight, with a significant positive correlation with copper and zinc.

Heavy metals in *Mercenaria mercenaria* and sediments of a bay in Massachusetts indicated that sediment cadmium content did not vary with season or site. Copper, iron, and lead varied with site, not season. Zinc concentrations were site dependent and seasonal. All tissue metal concentrations varied significantly with season . Zinc is regulated by the organisms. Cadmium and lead concentrations found in sediments and tissues were of similar order of magnitude suggesting that the organism does not regulate them. Copper and zinc were higher in the organism suggesting the two metals are accumulated and metabolized by *M.mercenaria* (Genest et al,1981).

Popham et al (1983) tried to determine the combined effect of body size, season, and location on trace element levels in *Mytilus edulis* Large mussels tend to have lower concentrations of copper than do small ones. This relationship has also been found in the freshwater clam (Foster et al,1978). Mussels have higher lead levels in summer. Trace metals other than lead and manganese are higher in winter than summer. Except for lead and zinc trace metal concentrations decrease with increasing size. These researchers feel that because mussels of the same shell volume can have different volumes of water , dry weights should be used when doing analytical calculations.

The Pacific oyster (*Crassostreas gigas*) was used to determine the uptake of chromium, lead, zinc, and copper from sediments (Ayling 1974). Depending on oyster size copper and chromium were accumulated to a maximum concentration. Lead was not absorbed through any identifiable process , and levels were comparable to those of the site. For 1ppm cadmium in the mud, the oyster accumulated 25 ppm (4-5 ppm wet weight). Cadmium and zinc accumulation was dependent on the amount available.

Simpson (1970), examined the uptake and loss of zinc and lead by mussels (*Mytilus edulis*) to determine a relationship between uptake, body weight and reproductive cycle. Mussels had spawned in May/June. When transferred to clean water copper decreased as weight was lost, but cadmium did not. From September to January the dry weight decreased with time. Seventy-nine percent of mercury was lost after 80 days in a declining temperature regime. Temperature has not been considered a factor in accumulation by other researchers (Smith and Green,1975).

Accumulation of copper and zinc into soft body tissues of mussels was linear over 5 weeks, and proportional to the external concentrations (D'Silva et al ,1978). However, control mussels accumulated zinc as well.

In a study of *Crassostrea virginica* and its ability to accumulate lead it was found that after 20 weeks there was a significant linear relationship between lead uptake and the lead concentration in seawater (Zaroogian et al,1979). Tissue concentrations increased when exposed to seawater containing 1.0 ug Pb kg-1.In the mussel the highest selenium (Se)-75 concentration was in the visceral mass, while the highest concentration of selenium was in the mantle. Uptake resulting in high concentration in the visceral mass is thought to have been food chain related.

Schulz-Baldes (1974), experiments were designed to determine uptake and loss of lead from the common mussel *Mytilus edulis* He used several concentrations of lead and noticed that all uptake patterns were similar over 6 weeks. For the first 40 days uptake was linear. For 35 days small mussels took up 2.5 times faster than large ones. After 5 weeks in lead, concentrations began to decrease. The kidney showed the highest rate of uptake and the highest rate of loss. The digestive gland, and adductor muscle indicated losses as well. The gill rate was low. It seems the loss of lead is closely linked to the internal lead concentration.

Depuration of cadmium from the oyster *Crassostrea virginica* is affected by salinity, is slow, and may take place in a biphasic manner (Mowdy,1981). Loss was rapid in the first two days and after forty-two days to seventy-four days, but stopped from 43-60 and 74-104 days. Cadmium may be found slowing the process down.

Luten et al (1986), examined the accumulation, elimination, and speciation of cadmium and zinc in *M.edulis* In the natural environment cadmium is present in the cytosol of mussels, bound to a protein smaller than metallothionein. Cadmium and zinc are taken up linearly but are not eliminated. The cytosol behaves as a strong complexing agent for cadmium, a significant amount is still available for DPASV. This has been postulated by Adams et al (1981) for freshwater clams.

Ober et al(1987), compared molluscs, crustaceans and shellfish species with respect to copper, zinc, cadmium, lead, mercury, nickel, antimony, selenium, iron, and chromium. Cadmium, lead, copper, nickel were highest in molluscan species; zinc and iron highest in crustaceans; copper and antimony accumulated similarly by molluscs and crustaceans.

Talbot (1987 (b)) has been able to develop a quantitative relationship between total recoverable cadmium in seawater and its concentration in the mussel. He has determined that the seawater concentration should not be greater than 0.2ug/L if the mussel is to remain at or below a cadmium concentration of 2mg/kg wet weight. In order to follow this guideline the weights, lengths and season are important factors.

Cadmium uptake in *Crassostrea virginica* was highest in the gill, mantle, hepatopancreas, and least in the adductor muscle (Hung-Yen-Wan ,1982). A cadmium level of 0.05 ug/ml was used with the chelating agents EDTA, NTA and humic acid for 40 days. He concludes that the chelators decrease accumulation with the exception of the adductor muscle. The accumulation was evident at any temperature but the highest rate was at high temperatures.

The major route for bioaccumulation of dissolved trace metals in marine bivalves is via the gills (Hardy et al,1981). If sediments are absent gills rapidly accumulate cadmium from seawater. Bioaccumulation is linear over a 48 hour period. If sediments are added the cadmium absorbs to the sediment particles and is unavailable.

Nolan et al (1983), investigated the mechanism of uptake of cadmium by *Mytilus edulis*. Levels of cadmium were increased over a 24 hour period. As the dose in the water increased the amount of cadmium bound to metallothionein increased. Cadmium accumulates in subcellular fractions but mainly in cytosol bound to metallothionein (a class of low molecular weight, sulphydryl-rich proteins). Gradually the cadmium increase causes the heavy molecular weight fraction to increase to the point where other processes begin to be affected. Nolan et al (1983) outline 3 patterns of uptake:

1) shell- adsorption occurs binding to organic material on the sides;
2) mucous on gills and mantle - have an affinity for cadmium and work to minimise changes in cadmium in water;
3) hepatopancreas and kidney- uptake cadmium at lower concentrations but more rapidly than the gills/mantle, tend to level off at a higher dose.

Watling et al (1983) have been working with the bivalve *Donax serra* to confirm their use as biomonitor. In a three week exposure, tissue cadmium concentration increased with increasing concentration in the test solution. The order of accumulation was: gill>>> digestive gland> muscle> mantle> gonad> foot> syphon.

Zaroogian (1980), found higher cadmium levels in smaller animals. At higher concentrations variability increased. When gills reached high levels cadmium was bound to mucous sheets. They concluded that weight decreases were reflected as increases in cadmium concentration. Phillips (1976) suggests the same. Also cadmium was distributed as visceral mass>gill>mantle. At temperatures less than 6 degrees Celsius *C.virginica* was not a useful cadmium indicator. They believe size is important and small animals are best used. There was no value in using specific tissues over whole soft parts.

Mussels exposed to cadmium for 25 and 50 days had filtering rates altered after 100 ug/L (Sturensson ,1978). Only small amounts of cadmium were taken into the carbonate crystal lattice. Field mussels grew faster than caged mussels. Cadmium has been well-studied in the marine environment indicating uptake to vary depending on temperature, animal size, concentration, presence or absence of sediments. Bioaccumulation has begun after 24 hours exposure and up to five weeks.

Pentreath (1973) examined the mechanism of accumulation of the radionuclides 65Zn, 54Mn, 58Co, and 59Fe by *Mytilus edulis*. The greatest accumulation of radionuclides in *M.edulis* was in the stomach and digestive gland. A weight loss affected the digestive gland and iron in the foot. Iron conjugates in the bysuss gland area of the foot. Pentreath was able to demonstrate that nuclides are accumulated via particulate matter sequestered by the mucous. He feels water plays a very minor role in the accumulation of nuclides.

The Eastern oyster accumulated significant levels of mercury when exposed to mercuric chloride (Mason et al, 1976). Accumulation occurs in two distinct phases, linearly over eleven days. Phase one is rapid uptake, then reverses and shifts to a linear irreversible form. Since no food was involved in this study, uptake is believed to be through gill and mantle tissues via water.

Ostrea edulis accumulated mercury in 48 hours through the gills. Protein presents binding sites, reduced when the animals are starved, and causing less uptake to occur (Wrench, 1978). Wrench proposes that the gills present a high degree of permeability passing mercury on to other tissues where the amount taken up is determined by the binding capacity. The digestive gland has high protein content and there represents a basis for high concentrations and equilibrium.

When mercury levels are low a loss of iron occurs from the mantle fringe in mussels. Cytosomal uptake seems to be the mechanism for mercury uptake (Fowler et al, 1975).

The eastern oyster (*Crassostrea virginica*) accumulated organic and inorganic mercury compounds in the gills in excess of 0.5 ppm (Kopfler, 1974). *M.edulis* determined the presence of mercury in water which indicated no mercury. After a 100 day exposure period levels were the same as the natural mussels of the area (Davis et al, 1978). Mussels exposed to 20 ng/L showed a significant change in mercury concentration in 20 days.

Uptake of mercury by the intertidal mussel (*Mytilus californianus*) was studied by suspending the animals at four depths for 24 weeks (Eganhouse et al, 1978). There was no relationship to depth. In two to five weeks the digestive gland had accumulated mercury;

after 12 weeks the adductor muscle mercury had not increased substantially. The gonadal tissue mercury levels increased gradually over 12 weeks, highest levels found at 16-20 weeks.

In a marine simulated environment *Mytilus galloprovincialis* LMK was exposed to 10-100-200 ppb of mercury, rapidly accumulating to 40,000-100,000-130,000 ppb (Majori et al, 1973). At 500 ppb uptake diminished as a result of animal health. The maximum non-lethal concentration of 200 ppb of Hg* allows the mussel to deaccumulate from 112,000 ppb.

Mercury uptake by the various marine bivalves studied indicated the gills to be rudimentary in mercury uptake and bioaccumulation to occur from 48 hours to 16-20 weeks. Mercury and iron relationships exist in the organisms, while selenium and mercury work antagonistically on accumulation.

Watling et al (1982), wanted to determine the use of the brown mussel (*Perna perna*) as an indicator organism for South Africa. Mussels of a similar size range were chosen to examine filtering rates. Manganese caused a steady increase in filtering rate; selenium and mercury complexed and worked antagonistically. Increased mercury decreased filtering, while moderate selenium concentrations showed a dramatic filtering rate increase. Smaller mussels were most sensitive to copper. The organic mercury compounds had similar effects on filtering as mercuric chloride. Arsenic (arsenate) and manganese had no effect on filtering rates in the smaller organisms. If these metals have an impact on filtering rates in freshwater organisms, additional research should be done to determine the impact on rates of other contaminant accumulation.
Grieg et al (1978), attempted to determine if silver and copper were taken up from sediments. *Crassostrea virginica* exposed eleven weeks to muddy sediment accumulated no significant levels of silver or copper. When exposed to sandy sediments accumulated no copper. When transferred to clean water, oysters tend to retain their metal content.

Luten et al (1986) examined *Mytilus edulis* twice a year at nine sites for four years and detected mercury, lead, cadmium, copper and zinc. Pre-spawning cadmium and lead levels

were lower than those spawning. The seasonal variation in soft tissue weights with the trace metal burdens was examined in somatic and gonadal tissues over a nine month period (Latouche et al ,1981). Gonadal burdens of copper did not show seasonality, others were highest in late winter/early spring at the time of gametogenesis. Somatic burdens of nickel, manganese and zinc were greatest in early spring and managanese appeared to increase later in the year. The somatic burdens of copper, cadmium and vanadium fluctuated but with no regularity. Metals appeared more abundant in the somatic tissues. Tissue weights increased with reproductive cycle, associated with increases in gonadal material and with low metal levels and corresponding decreases in metal concentrations over all. Phillips (1976) and Zaroogian (1980) suggest that metal levels do not actually change but appear so by the weight differences. Gonadal and somatic weights should be analyzed separately and sampling should take place the same time each year from the same population. Tissue weights should be recorded.

Carmichael et al (1979), investigated the use of the marine bivalve kidney as a metal indicator. However, the two, *Argopecten irradiens* and *A.gibbus* display differences in calcium, manganese, cadmium, copper and chromium. This evidence adds creedence to Phillips' (1973) comments on the differences between closely related organisms.

Strong et al (1981) studied variations in the correlations of body size with concentrations of copper and silver. Correlations (metal concentrations/body weight) varied among species and with the metal. They point out 4 conditions which are typical of the metal/body size relationship:

1) in short term exposures (in the laboratory) metal uptake by smaller individuals of many species is more rapid than by large ones;
2) growth can dilute metal levels, especially where growth is quicker and tissue is added faster than metal; younger bivalves grow quicker than older ones;
3) if there is a positive correlation between size and metal concentration it may mean a long-term chronic exposure to a metal depending on its uptake rate;
4) some metals may equilibrate and therefore present a positive correlation, this occurs in a metal enriched environment.

"The optimum way to represent tissue metal concentrations in indicator organisms is probably best determined by the objectives of the representation." (Strong et al,1981)

Comparing chronic contamination among stations must take age into consideration , whereas temporal fluctuations must include the use of several size-classes of organisms. Strong et al(1981) believe collecting a range of sizes is the best strategy in a monitoring program.

Biomonitoring programs are useful if procedures and costs can be reduced, therefore sampling and analytical methodologies must be improved when possible. Arsenic analysis is not routine nor easy analytically , therefore Latouche et al (1982) investigated the need to separate tissues for analyses. Arsenic was positively correlated with somatic tissue weight. The somatic and gonadal tissues were similar but the somatic tissues are always higher for other metals. Their work suggests it is unnecessary to separate tissues for arsenic determinations.

Using radiotracer arsenic Unlu et al(1979) traced the factors affecting the flux of arsenic through the mussel *Mytilus galloprovincialis*. Increased temperature increased the rate of uptake until 17 days when the uptake rate decreased to reach isotopic equilibrium. Arsenic as arsenate is accumulated very slowly and is not proportional to water concentrations. Arsenic is also accumulated only by the soft parts. Smaller mussels accumulating more arsenic than larger ones. This is also noted with copper. Arsenic increases at low salinities even when weights stay constant. Loss of arsenic is related to temperature until 13-20 degrees Celsius then no relationship exists. This study concludes that bysuss formation/excretion is an important way to lower arsenic levels.

The oyster (*Crassostrea virginica*) and mussel (*Mytilus edulis*) were exposed to ambient seawater conditions in the laboratory and to concentrations of nickel expected to be found in the environment (Zaroogian et al,1984). They found that there was a significant linear relationship between soft tissue nickel concentrations in both animals, and seawater. The seawater concentrations were 5 and 10 ug Ni/kg while oysters accumulated 9.62 +/- 3.56 and 12.96 +/- 5.15 ug Ni/g dry weight, and mussels 10.40 +/- 2.66 and 16.43 +/- 3.13 ug Ni/g dry weight.

The uptake and accumulation of nickel by these two animals takes place quickly in the first two weeks after exposure has ended. Nickel loss does not seem to be time nor temperature dependent. *M.edulis* is considered the better of the two organisms for use as an accumulator of nickel because it accumulates nickel to a greater level and shows less variability amongst its number (Zaroogian et al,1984).

Seasonality of organisms and the season selected for exposure is important in planning a biomonitoring program. Mix et al (1982), tried to determine if seasonality was an important factor in benzo(a) pyrene (BAP) uptake. Samples of *Mytilus edulis* were collected at ten day intervals over a number of months pre- and post- spawning. They separated the tissues into somatic and gonadal and analyzed them for benzo(a)pyrene. The majority of BAP was found in the somatic tissue indicating that seasonality had no affect on concentration of BAP accumulated by the mussel.

Kira,et al (1983) took mussels from an area of petrochemical industries and analyzed them for dibenzothiophene (DBT). In 4-8 days they accumulated 600-800 times the concentration in water.

Stainken (1976) used the soft shell clam, *Mya arenaria* exposing them to #2 fuel oil (naphthalene, methyl substituted naphthalene isomers). Clams ejected a considerable amount of mucous, reducing their filtering rate to 50-100 ppm. The first week of depuration was rapid, slowing after 14 days, although not all naphthalenes were gone.

The clam *Rangia cuneata* was exposed to BAP-C14 at 0.0305 ppm for 24 hours and accumulated to 7.2 ppm (mean) (Neff et al,1975). Nearly 75% of radioactivity was localized in the viscera (digestive system,gonads,heart) while the mantle, gills, and adductor muscles,foot each had 3.5-10% of total radioactivity. When exposed to "clean" water 70% was released in ten days and after 20 days only 0.1 ppm was left. Complete depuration to non-detectable levels was 30-58 days. It appears that marine bivalves accumulate certain organics rapidly up to eight days but then lose them again from 14-20 days.

Ekelund et al (1987), examined contributions from food, water and suspended particles to the deposit-feeding marine bivalve (*Abra nitida* Muller). Accumulation was higher in all experiments when suspended particles were added. Hydrophobic pollutants adsorb to suspended particles. Lindane, a non-hydrophobic pesticide is not absorbed to suspended particles.

Mytilus edulis were exposed to 29 ppb of polynuclear aromatic hydrocarbons. They were also present in long-term exposed mussels (123 ppb) (Livingstone et al, 1985). Lysosomal stability was significantly reduced in animals from both oil conditions. NADPH-CYTCRED activities increased then decreased under clean water conditions. These changes likely enhance metabolism.

Phillips (1976) is considered an authority on bivalves used as indicator organisms. He suggests that mussels not be used for copper monitoring in the marine environment because the animal regulates the copper. His studies also showed that seasonal weight variations are not indicative of metal content fluctuations. In other words the mussel weight changes over the year but metal content stays the same year around. Some rigid rules are set down by Phillips for sampling:

1) all mussels should be collected in a short period in the same season;
2) all samples should be taken in midwinter when mussels weigh the least but appear to have increased metal levels;
3) a minimum sample size should be te individuals of similar shell length and wet weight;
4) they should be taken from the same depth and areas of salinity;
5) do not use for copper monitoring.

Some bivalves accumulate certain metals rapidly while others do not. Copper and zinc appear to be regulated by the majority of bivalves studied and cadmium seems to have some relationship to gametogenesis and spawning in freshwater bivalves. Cadmium can have a biphasic uptake and/or linear uptake depending on the ambient concentration. Marine bivalves regulate copper so should not be used to monitor copper. Arsenic accumulations bear no similarity to environmental levels. Manganese and lead tend to be

associated with shell development. Smaller bivalves usually tend to accumulate greater concentrations of contaminants although they imply that age is the controlling factor, not size. Mercury has been reported as accumulating in a matter of two weeks in the marine environment while freshwater studies indicate weeks to months, and then only if the system is contaminated. Several organics have been shown to have rapid periods of accumulation and elimination. Two studies say that bivalves mirror the concentrations of contaminants in the sediments, while others, and personal experience have not found sediments to have any impact on accumulation. Metals seem to be associated more so with the somatic tissues than the gonadal ones. This may be related to cytosomal uptake.

Bivalves fit many of the criteria put forth as characteristic of a good monitoring organism. They are relatively easy to identify; large enough to provide adequate tissue for analysis; sedentary; filter feeding means contaminants can be taken in via water, food, or bound to particulate matter; hardy enough to transport and handle easily in the laboratory or field; they can be tagged or marked for experimental purposes; and have growth/stress rings for aging purposes as well as for slicing for contaminant analyses; and some gill-breathers or pulmonates are quite tolerant of low oxygen (*Amblema perplicata, Anodonta cataracta cataracta, A.grandis grandis, Sphaerium transversum, S.striatinum*) which suggests they could be useful in heavy industrial discharge areas.

4.9 Fish

Seelye et al (1982) used hatchery reared yellow perch (*Perca flavescens*) to evaluate contaminants released from dredged sediments. They make the following recommendations:

1) -provide consistency in size and origin of test organisms if bioaccumulation procedures are to be used for regulatory purposes;
2) -provide consistency in handling sediment in terms of oxidation or reduction of the sediments;
3) -use water of the same hardness and salinity as dredged area;
4) -use an exposure greater than ten days (time-series data should be collected to enable estimation of steady-state concentrations based on uptake patterns) (ten days did not allow for a pattern of chemical accumulation in fish).

Olsson et al (1978), emphasize the need for taking seasonal variation into account when looking at organochlorine accumulations in fish. Since organochlorines are lipophilic and fish weights change according to spawning season etc. a method of standardizing organisms is needed.

Caged yearling rainbow trout (*Salmo gairdneri*) and native fish species (white suckers, longnose suckers, flathead chub (*Hybopsis gracilis*) of the Athabasca River were sampled following blackfly larviciding (Lockhart et al ,1977). Rainbow trout accumulated methoxychlor in the liver. Mussels, crayfish, and aquatic insects did not accumulate methoxychlor. Caged native fish did not accumulate methoxychlor to the same degree as the wild native fish. It seems caging of fish may underestimate fish contamination. Chub and suckers were not successful fish species for caging, causing serious abrasion to themselves on the cage sides.

Fathead minnows (*Pimephales promelas*) caged in the field and tested in the laboratory showed marked differences in their response to cadmium (Sullivan et al ,1978). In the wild, dissolved cadmium was 3.3-43.4 ug/L (ppb), 48 ppb in the laboratory. Whole background levels in lab and field controls averaged 0.29 and 0.002 ppm respectively. Field fish reached 3.19 ppm (dry weight) cadmium in 12 hours, laboratory fish 8 days. Lake water was 3.4 degrees Celsius higher , and turbidity greater than in the laboratory. They hypothesize that these differences stressed the fish to increasing metabolism and uptake of cadmium, concluding that laboratory studies do not reflect field work.

Trifluralin accumulation was proportional to the concentration in water with reversible accumulation (Spacie et al ,1979). Large river fish had slower rates of trifluralin clearance than lab minnows.

Seasonal variation in PCBs over a seven year period indicated levels of PCBs peaked in the spring and decreased rapidly back to base level (Olsson et al ,1978). It could have been caused by increased spring runoff or increased activity of fish due to spawning. There was no correlation between DDT and PCBs with size, sex or age. There was no relationship between PCBs and fat levels, as determined by Suns et al (1981).

Forty-five freshwater fish of various sizes and types were analyzed, fish tissues separately from wastes for each fish (Zamojski et al,1986). Each fish species had higher levels of HCH, DDE, DDD, DDT and total DDT in wastes than in tissues. Wastes of those eating primary producers were lower than those eating predaceous species. Wastes indicated a correlation between higher fats and higher organochlorine levels than tissues. Mercury accumulation was dependent on the type of food eaten.

Caged juvenile rainbow trout exposed to linolenic acid reached a maximum concentration in 12 hours. Residues were found in gills at levels greater than blood and viscera, with little in muscle (McLeay et al,unpublished). Other fish were exposed four days to purified dehydroabietic acid. The highest accumulation was in the blood plasma, liver, kidney, brain and muscle. Excretion was predominately through the hepatobiliary route in a conjugated (detoxified form). In two days rainbow trout levels were similar for abietic acid, neo-abietic, pimaric, sandaracopimaric, isopimaric, levopimaric and palustric. Concentrations did not increase with exposure past two days. Indigenous perch (*Perca fluviatilis*) levels were similar to caged rainbow trout. Lockhart et al (1977) found indigenous fish to be higher in concentration for organics than were caged fish. Chloroguaiacols accumulated in pike liver tissue and muscle. Chlorophenols are conjugated to glucaronides and sulfates in liver for biliary and branchial excretion; only a small portion is excreted in an unconjugated form. Guaiacols are lost up to 75% in the first day after transfer to uncontaminated water.

The bioaccumulation of radium 226, added to a lake in the Experimental Lakes Area (ELA) of northern Ontario, was similar for lake trout, white sucker and lake whitefish but had no dependence on water concentrations (Hesslein et al,1984).

Caged northern pike (*Esox lucius*) in the English-Wabigoon River System were exposed to mercury and selenium for 3 weeks (Turner et al,). Selenium reduced mercury accumulation via food intake. When using fish, as with other organisms, it is necessary to know what other metals or interacting parameters there are in order to interpret the results.

Spottail shiners (*Notropis hudsonius*) and yellow perch (*Perca flavescens*) have been used since 1975 by the Ontario Ministry of the Environment to investigate point and non-point source contaminants for spatial and tempo. al trends. The young fish are of known age. They have been useful for heavy metal and organochlorine pesticide, PCBs, and mirex determinations. Used yearly with the same sizes, species and time of year collections some variability inherent in field collections are eliminated (Suns et al,1978; Curry et al,1979; Suns et al,1980(a); Suns et al,1980(b) ; Suns et al,1981; Suns et al,1983(a); Suns et al,1983(b); Suns et al,1985(a); Suns et al, 1985(b); St. Clair River Pollution Investigation,1986;). The young fish have also been used to look for chlorinated phenols, polychlorinated dibenzofurans, trichlorotoluene, chlorobenzene and 2,3,7,8-TCDD (Suns et al,1985(a)(b)). K.Suns (personal communications) indicates spottail shiners are useful for lead (although organic lead changes are seen very rapidly), mercury and cadmium, but other metals are regulated by the fish so levels are not true reflections of the environmental levels. Fish generally are not useful for chlorinated phenols. Chlorophenols are readily metabolized and excreted.

Interspecies comparisons are being developed with emerald shiners (*Notropis atherinoides*) and common shiners (*Notropis cornutus*) for selected metals, organochlorine and other organic contaminants.

The young fish program has been well accepted for use in nearshore waters, and programs have been started in the United States states bordering the Great Lakes to develop a database of contaminants in those waters.

Sport fish are generally used as indicators for consumption guidelines in Ontario. It is difficult to interpret the sport fish contaminant levels since the fish migrate and may accumulate body burdens of contaminants from areas of heavy industrialization.

Linder et al (1985) exposed rainbow trout to anthracene and anthracene mixtures finding that less anthracene was accumulated in mixtures than alone. In the mixture, anthracene could have been absorbed to suspended particles and unavailable to the fish. In the laboratory study, fish were starved causing an accumulation of anthracene in the bile. If fish had been feeding the bile would have been released and metabolites excreted. Depuration rates were higher in fish exposed to mixtures, perhaps due to induction of the mixed-function oxidase enzyme system.

Bruggeman et al (1984) looked at the bioaccumulation of super-lipophilic chemicals in fish. The high chlorinated biphenyls showed low clearance rates with uptake from contaminated food. Some of the chemicals (hexabromobenzene, octachlorodibenzo-p-dioxin and tetradecachloroterphenyl) were accumulated in live and dead fish. Some of the other chemicals were found in the same levels in both dead and live fish. This suggests uptake not to be a physiological response for all chemicals, but a passive action of adsorption.

Dichlorobiphenyl and pentachlorobenzene were quantifiable during dietary administration but were cleared in 14 days. Teter-,hexa-,octa-, and decachlorobiphenyl gradually increased with exposure and gradually decreased after dosing stopped. The most lipophilic were still present at the end of the experiment (84 days). Moderate lipophilicity is considered to be a logP of between three and five. They believe uptake is restrictive to molecules of certain sizes. Geyer et al (1985) tried to determine if their was a relationship between fish and its lipid content, and the potential for a chemical to bioconcentrate. They found that for 1,2,4-trichlorobenzene there was a significant positive correlation between the lipid content of the fish species and their bioconcentration factor (BCF). The log BCF on a lipid basis agrees well with the log n-octanol/water partition coefficient. Variability between fish species is reduced if you look at lipid rather than wet weight for bioconcentration. Bioconcentration excludes consumption and absorption of contaminated food (Veith et al,1979).

Marine animals accumulate PCBs and DDT differently to freshwater organisms, since inconsistencies exist in animals from the same area (Goerke et al,1979). PCB concentrations based on wet weight are positively correlated to lipids, PCB concentrations based on lipids increase from bivalve to fish and appear to be correlated to trophic level.

Baltic salmon (*Salmo salar*) and Bothnian Bay trout (*Salmo trutta*) muscles, livers and unfertilized eggs were analyzed and found to have PCB, DDT, HCB, lindane, 2,3,6-trichlorocymene and 10 chlorophenols (Vuvirnen et al,1985). The chlorohydrocarbons were positively correlated with weight and fat contents. Vuvirnen et al (1985) agree with Goerke et al (1979) that in studying chlorophenols it is better to look at fresh weight rather than lipids. This applies to fish from the freshwater environment as well.

Polycyclic aromatic hydrocarbons have been studied using marine fish (*Gielichthysmurabilis*-mudsucker or sand goby, *Oligocuttus maculosus*-sculpin, *Citharichthys stigmaeus*-sand dab). PAHs are taken up through the gills of fish, metabolized by the liver, and transferred (hydrocarbons and metabolites) to bile and excreted. Gall bladder is the major storage site (Lee et al, 1972). Uptake in the laboratory occurred within minutes, excretion was through the urine.
Rainio et al (1986) analyzed for PAHs in mussels, Baltic herring (*Clupea harengus*), pike-perch (*Stizostedion eucioperca*), and burbot (*Lota lota*). Very few of the PAHs were found in fish muscle, tending to accumulate in liver and gall bladder.

DouAbdul et al (1987) analyzed fish in the Arabian Gulf for PAHs. They also found that the PAHs were accumulated and rapidly excreted. PAHs are of high molecular weight, nonpolar and with low water solubility. They can still accumulate in fish but are metabolized and excreted as water-soluble metabolites. Another study looking at benzopyrenes and naphthalenes indicated that the fish were able to eliminate naphthalene and metabolites faster than benzopyrene and metabolites. The major metabolite of H-3,4-benzopyrene is H-7,8-dihydro-7,8-dehydrooxybenzopyrene and of naphthalene is 1,2-dehydro-1,2-dehydrooxynaphthalene.

Monocyclic aromatic hydrocarbons (MAHs) are accumulated through water (Whipple et al 1981). Uptake is rapid and excretion, although rapid, is somewhat slower than uptake (48 hours). The major route of excretion of metabolites is via the bile to the intestine and through the feces. It seems larval fish have some difficulty in metabolizing and excreting MAHs likely due to incomplete development of their digestive system.

Fish (*Valencia hispanica*) from a marsh area in Spain were analyzed for mercury. There were no weight/mercury, length/mercury relationships perhaps due to the area not being contaminated with mercury. These relationships are apparent when there is contamination (Rincon et al, 1986).

The literature has indicated discrepancies between results from wild fish and caged fish even though exposed to the same contaminant. Caged fish likely underestimate what is in the system. Cadmium in the field has been shown to accumulate in 12 hours. Radium levels

in fish are related to calcium concentrations in the fish. Chemicals associated with the pulp and paper industry are found to be quickly accumulated (2 days) and eliminated . Chlorophenols in fish are conjugated by the liver activity and readily excreted. It has been suggested that if looking for chlorophenols in fish, fresh weights not lipids should be examined. Many organics (organochlorines in particular) are accumulated by fish in lipid stores. PAHs are metabolized by the fish liver and excreted or stored as metabolites. The PAHs are usually stored in the liver or gall bladder not fish muscle, therefore a monitoring program taking and analyzing fillets is unlikely to find anything. Monocyclic aromatic hydrocarbons are rapidly accumulated and excreted via the bile, intestines and feces.

5.0 SPECIFIC CONTAMINANTS - RECOMMENDED ORGANISMS

Tables 3 and 4 represent the information from the literature pertaining to specific contaminants and accumulation/ equilibrium. They also include information on organisms regulating contaminants, and suggestions for using/not using certain organisms. There are many gaps in the available information, but what does not exist can be useful in eliminating what not to use for biomonitoring depending on the project objectives.

6 0 DISCUSSION

The review of literature on biomonitoring and potential biomonitoring organisms indicates a considerable amount of research done in the marine environment but relatively little for freshwater. The freshwater studies predominately deal with metals in bivalves and organics in fish.

As seen in the literature that does exist even very closely related organisms are different in the way they react to a contaminant. This can be seen from phytoplankton through to fish. These differences, even within species, must be considered when selecting the best possible organism(s) for a biomonitoring program. Consequently, depending on the objectives of the program, a number of species may be used. The objectives of a program may include:

- identification of a specific contaminant source;
- presence /absence of a contaminant or host of contaminants (organics, metals);
- determination of concentrations of contaminants;
- trends in contaminant levels with time and space (short-term/long-term);
- or, any combination of the above.

From the information available, organisms may meet the criteria for a good biomonitor as outlined by Phillips (1973), or only meet one or two and be considered impractical for use on a large-scale ie. province-wide basis.

Neither phytoplankton nor zooplankton fit many of the criteria of a useful biomonitor. They are sensitive to certain metals and pH changes; they are short-lived; small in size requiring large numbers for analyses; they are mobile (actively and passively); and single species samples are impossible to collect (species variations in contaminant uptake necessitate a single species for a study).

Macroalgae (filamentous algae) accumulate contaminants in proportion to the water . They have also been known to regulate metals (manganese, iron), and are influenced by metal-metal interactions (Phillips,). Macroalgae are restricted in their habitat locations by nutrients, and physical parameters which do not always exist in areas requiring environmental monitoring. These factors reduce the usefulness of this organism in a biomonitoring study of a site-specific nature.

Macrophytes have specific requirements for growth excluding them from many of the areas where biomonitoring investigations must take place. They are relatively short-lived; appear to accumulate from sediments only; accumulate in the roots; and do not accumulate in proportion to the surrounding aquatic environment.

The freshwater aquatic insect information is also sketchy. Mayflies do concentrate contaminants to levels reflecting levels of the surrounding water, but they do not meet many of Phillip's other criteria. A short life span complicated by larval transformation restricts use of these organisms to specific time periods. A relatively small size means a large sampling effort and/or successful culturing facility. Handling and transportation are not easy and viable alternatives. The use of indigenous animals may be restricted by insect drift complicating result interpretation.

Crayfish offer several advantages for use as a biomonitor. They are large enough for individual analyses; they are detritivores accumulating from sediments , water , and suspended particles; they can be handled and transported easily, although cannibalism can occur in cages; sex differences in contaminant uptake do not appear evident; and, they have been shown to accumulate selected contaminants with respect to the surrounding environment. However, crayfish do regulate some metals, they molt losing contaminant body burden rendering them susceptible to disease and predation, and the marine literature suggests the possibility that freshwater crayfish may metabolize organics as do marine crustaceans. Overall, crayfish are not considered a practical alternative to province-wide biomonitoring.

Worms such as the marine *Nereis diversicolor* have been known to regulate metals (Phillips,). The freshwater information is limited, but factors such as size; associations with the sediments ; and , the percentage of contaminant found in the gut in relationship to the whole animal, suggest they also are inappropriate for routine biomonitoring.

Leeches have proven to be excellent monitors for chlorophenols. They are plentiful, easy to transport and handle, of sufficient size to produce an adequate sample, starvation resistant, and are relevant to the public as fish bait. From practical aspects they are an ideal biomonitoring organism, but additional research is required for use with organochlorines and metals.

Clams also meet many of the characteristics of a good biomonitor. They are large enough to provide an adequate sample, easily aged, ubiquitous, sedentary, represent uptake via food, water, and particulate material, easy to transport and handle, they can be caged with or without sediments, and do accumulate metals and organics (particularly organochlorines) in relative proprtion to their environment.

Fish have been considered in this review, but are considered as long-term biomonitors. Short-term biomonitoring involving caging of fish is possible but can be labour intensive and expensive. There are discrepancies in the literature as to the comparability between caged and wild fish concentrations.

Bivalves and leeches seem to have the most potential as biomonitoring organisms for routine, regulatory monitoring. Although there is some conflicting information on bivalves and use as biomonitors (marine and freshwater), there is a considerable bulk of information available. The largest stumbling block is the wealth of information on various species and contaminants but no focused work (with the exception of the Ministry of the Environment's work) on a specific species or two and a selected list of contaminants.

The reviews available which provide information on mechanisms of uptake and elimination relate to the marine environment. The diversity of responses, even within species, rules out direct application to the freshwater environment, but information is outlined here for speculative purposes.

Marine organisms possess a variety of mechanisms for accumulating and metabolizing toxic metals from the environment. Fowler et al (1981) outline three major intracellular compartments responsible for trace metal accumulation:

1) calcium phosphate granules and concretions - the kidney of bivalve molluscs appears to have calcium phosphorus concretions as does the hepatopancreas of crustaceans. The calcium granules detoxify the contaminant. Cadmium for instance, may be detoxified and stored in the digestive gland of bivalves;

2) lysosomes - play a role in intracellular compartmentation of iron, mercury, lead, copper, and zinc in marine invertebrates;

3) low molecular weight metal-binding proteins (6-10,000 MW) have been found to bind cadmium, copper, manganese and zinc in various organs of marine species.

The affinity of metals is for subcellular proteins and other molecules, and not on lipid-water partitioning as is for organochlorines (Phillips,). The detoxified materials can be stored as intracellular granules in membrane-bound vesicles, in skeletal material (bivalve shell, crustacean exoskeleton), or in lipid stores.

The cytochrome P-450 monooxygenase or mixed function oxidase (MFO) system is involved with the detoxification of foreign organic compounds taken up by the tissues (Livingstone et al,1985). This system is found in fish, crustaceans, polychaete worms, bivalves and gastropod molluscs. It may take several weeks of exposure to induce any of the systems which exist for detoxification of metals or organics. Animals that have detoxification systems may not be as suitable as biomonitors unless patterns can be established from previous studies to know when these systems are induced. If the animal can be taken before this process begins, the subsequent results provide the monitoring information required.

No one organism can be said to display this system for all contaminants. This is why the information provided in Table 3 has been compiled. In planning a study samples would be collected before detoxification and equilibration occurs.

Bayne et al (1979) says although some people do not feel that bivalves have the biochemical capacity to metabolize contaminants, others have actually recorded oxidation of aldrin to dieldrin in vitro (*Anodonta* sp., *Mytilus californianus* and *M. edulis*). If it is

true that they do not metabolize organic contaminants then levels accumulated must depend on lipid-water partition coefficients (Bryan, 1979). Although there are no quantitative differences in lipids between freshwater and marine organisms, there are differences in the fatty acid component of the lipids. Freshwater organism lipids contain 18:2, 18:3, 18:4 acids while marine lipids have long chain polyunsaturated acids. These differences are related to diet (Phillips,).

If an organism is large it has a small surface area to volume ratio, and therefore equilibration of residues by lipid-water partitioning at the body surface will be a slow process. The amount of lipid in organs may vary, accounting for differences in uptake. Similarly organisms such as fish have higher lipid contents with age and can accumulate more organics than a younger member of its species. This is why it is important to use the same size or age class each year. The use of lipid content versus wet weight in bivalves could eliminate sexual differences for organochlorine determinations.

Contaminants once metabolized can be excreted or lost by different routes: diffusion across the general body surface and gills, via mucous secretions, in the feces,and urine. The lipophilic contaminants can accumulate in eggs and be eliminated as they are released (Sastry et al, 1987). Several metals are associated with shell and exoskeleton, the latter is lost during the molting stage in crustaceans and aquatic insects.

There are many factors which require consideration when planning a program and when interpreting the results:

1) **hydrophobic contaminants can adhere to suspended solids or sediment particles**-These are essentially unavailable to most organisms but the filter-feeders. A monitoring exercise without a depuration period could indicate higher levels of associated contaminants than are biologically available. If using worms, much of the contaminant can be in the gut and not a true reflection of what is biologically available, therefore a period of depuration is recommended;

2) **speciation of trace metals**-a number of forms of a metal might be dominant under conditions of low pH; high sediment organic content; presence of other metals; and anoxia. These can affect the biological response eg. the free cupric ion or dissolved copper species determines toxicity to an organism; mercury methylated by microbial activity in highly organic sediments is more toxic than inorganic mercury;

3) **metabolic rate**-smaller organisms tend to have a higher metabolic rate than do larger ones of the same species. Uptake of contaminants is generally quicker using small or younger animals.

Recent work by Mohan et al (1987) indicates that freshwater bivalves have "inherent tissue specific resistance potentiality to withstand ambient pesticide toxicity by suitably modulating its metabolic profiles." These adjustments may help the animal mitigate pesticide toxicity and increase its survival capacity. Implications exist here for biomonitoring programs related to pesticides, however additional information and clarification is necessary from Mohan et al (1987).

In the course of this review it has become clear that the Ministry of the Environment has a considerable amount of data from past monitoring programs, and information to be gathered from 1987's field season (which included use of clams and leeches). This information is considered to be the most potentially useful for biomonitoring decisions.

To conclude this discussion, a number of points from the International Mussel Watch are outlined. This organization has used mussels (marine) in the United States and in several other countries for a number of years. Their experience in biomonitoring is invaluable and can serve as guidance for freshwater studies.

1) They consider 25 animals as an adequate sample.
2) Nitrates, phosphates,chloroform, carbon tetrachloride can not be monitored by bivalves.

3) Bivalves appear to have minimal ability to metabolize petroleum hydrocarbons.
4) Only gross contamination is picked up by mussels (metals).
5) Loss of metabolites during haemolymph loss in the shucking process is a concern when using bivalves.
6) Samples should be taken during a period of least change (ie. winter months).
7) They use a set size of 50-80 mm.
8) Use of immature bivalves removes potential sex differences possible in accumulation during gametogenesis/spawning.
9) A 24 hour depuration period is important but requires care if you looking for hydrocarbons or organochlorines.
10) Both wet and dry weights should be determined.
11) Use of individual tissues is only necessary if very detailed information is required.
12) Use of shells as indicators is difficult (cleaning is difficult, analyses of the matrix is complicated) and not recommended.

7.0 CONCLUSIONS

The bulk of the biomonitoring research pertains to molluscs and the marine environment. The freshwater-related literature is scattered in scope and direction. The most consistent approach , and established database of contaminant monitoring using biological organisms, lies with the Ontario Ministry of the Environment, Water Resources Branch.

On a global scale the use of yellow perch, spottail shiners, and *Cladophora* provide a well-developed database of temporal and spatial contaminant trends in the province. Short-term, temporal and spatial biomonitors such as clams, can provide a database for site-specific situations. The clam has proven itself as a useful tool for organochlorine and selected heavy metal contaminants. The clam data can be consolidated to provide a database established in terms of contaminant, exposure period, geographical location, and contaminant accumulation. The gaps in this particular database of clam information will emphasis areas of further research outlined from this report.

The promise shown by the use of freshwater leeches in accumulating chlorophenols can be exploited. Their simplistic structure allows for uptake and accumulation of only water-soluble contaminants, with no facility for metabolizing them. Consequently the contaminants accumulate and provide investigators with information of contaminants in the aquatic system.

Depending on the biomonitoring program objective, clams and/or leeches caged together, may provide the best possible solution to short-term, site-specific biomonitoring. They are inexpensive, easy to handle and transport, of a size to provide a good analytical sample, hardy, detritivores, and ubiquitous in the aquatic environment.

Aquatic worms aquatic insects, crayfish and macrophytes should not be eliminated as biomonitors. Although the literature is lacking in areas, these organisms do meet criteria established by Phillips (1973). Aquatic worms and macrophytes are best used in investigations of sediment contaminant contributions to the aquatic system. Aquatic insects and crayfish may be best used investigating selected metals under controlled conditions such as laboratory biomonitoring studies.

The filamentous algae and young fish can continue to be used as "watch dogs" of contaminants over large areas and through time.

8.0 CURRENT TECHNIQUES (CAGES, ETC.)

The Ministry of the Environment's current biomonitoring programs include simple techniques but can provide considerable information. They are the:

1) spottail shiner (*Notropis hudsonius*) surveillance - Great Lakes
2) yellow perch (*Perca flavescens*) surveillance - inland lakes
3) *Cladophora* surveillance - Great Lakes, connecting channels, and Georgian Bay
4) the sport fish surveillance - inland lakes, Great Lakes
5) site-specific studies using caged clams, leeches, and fish

The first three surveillance programs provide clues to the source of the contamination by strategically locating collection sites. They represent biomonitoring programs of wide scope, temporally and spatially, answering questions such as:

-What is present/absent since the last survey?
-Have the levels increased/decreased? (barring no changes in analytical technique)

The fourth relates general information for consumption guidelines. Program 5) serves to pinpoint pollution sources and provide uptake information on a short-term basis.

Collection techniques for these programs are simple - trapnets, seine nets for 1) and 2); gill nets for 4); manual collections for 3); caging organisms or hand-picking indigenous organisms for 5). These are simple programs and relatively inexpensive (other than for analytical costs), for the information they provide.

Not every STP discharge, or industrial outfall has a population of spottail shiners or growth of *Cladophora* located at their discharge. So, of the other biomonitoring organisms/methods included in the literature review and those currently in use by the Ministry of the Environment, caging of clams, young fish, and leeches are the most appropriate for short-term, investigative projects where metals, organics, and their contributions to the surrounding aquatic environment are questioned.

In selecting the biomonitoring tool for use, the first step is to determine the objective of the monitoring exercise. The organism(s) to be used can then be chosen. Tables 3 and 4 provide guidance for selection of an organism best suited for the contaminant(s) of interest.

The Ministry of the Environment has spent considerable time developing the best possible techniques available for the biomonitoring organism(s) they have been using. The Aquatic Contaminants Section of the Water Resources Branch can readily outline the techniques they have used. The Research Advisory Committee has funded a study on clam cages and handling techniques (to be completed in 1988) which will provide useful information for those interested in clam studies.

The following is a listing of the references in this literature review pertaining to biomonitoring techniques:

Oikare, A. et al (1985)	- fish cage - rainbow trout
Hasselrot, J.B. et al (1974)	- fish cage - salmon
Turner, M.A. et al (19)	- cylinder - northern pike cage - yellow perch, pike
Mercury Pollution in the Wabigoon-English River System Lockhart, W.L.	- cages - crayfish - cages - rainbow trout, white sucker, longnose sucker, flathead chub
Czarnezki, J.M. (1987)	- cages - pocketbook mussel
Adams, T.G. et al (1981)	- cages - three ridge clam
Bedford, J.W. et al (1968)	- pens, monofilament lines - mussel
del Castilho, P. et al (1983)	- polyethylene baskets - mussels
Jacob, C. et al (1985)	- cylinder - leech
Nehring, R.B. (1976)	- livebox - mayflies
Dickson, K.L. et al (1974)	- live bags - fish plastic cones - snails

Colborn, T. (1982)	- fiberglas cages - insects
Ahlf, W. et al (1981)	- perspex tube - algae
Mix, M.C. et al (1982)	- bags - mussels
Simpson, R.D. (1979)	- plastic mesh cages - mussels
Heitmuller, P.T. et al ( )	- cage - any animal on sediments
Delisle, C.E. et al (1976)	- collapsible cage - insects
Luten, J.B. et al (1986)	- nylon baskets - mussels
Kauss, P.B. et al (1985)	- steel cages - clams
Inniss, C.S. et al (1978)	- cage - fish
Flood, K. et al (1986)	- cage - rainbow trout
Fox, C. et al (1987)	- cage - clams
Curry, C. (1977/78)	- cages - clams

9.0 EXAMPLES OF CURRENT BIOMONITORING RESEARCH AND FUTURE RESEARCH NEEDS

1) Environment Canada and the Ministry of the Environment are developing the use of leeches as biomonitoring tools, particular emphasis has been on their use with chlorophenols.

2) The Great Lakes Institute of the University of Windsor is investigating: the importance of sediments in contaminant uptake; seasonality as a factor in uptake; and, the comparability of *Lampsilis radiata* and *Elliptio complanta* as biomonitors.

3) Integrated Explorations Limited of Guelph is involved in determining temperature effects and procedural variations on contaminant uptake using *E.complanata*.

4) The Department of Biological Sciences, University of Windsor is developing biomonitoring protocols for use of adult aquatic insects - this includes collection procedures and the importance of seasonal variation and insect dispersal.

Future Research Needs

1) culturing of freshwater clams -
Balsam Lake has had, and will likely have, considerable pressure placed on its clam population since it is currently the source of organisms for the province's biomonitoring programs. This pressure, combined with the fact that the yellow perch is the only known host of *Elliptio complanata*'s larval stage, and that the yellow perch population may diminish due to pollution, indicate a need to investigate culturing possibilities.

2) development of other clam species as biomonitors -
Another ubiquitous clam species should be selected for comparative work with *E.complanata* and in conjunction with the work underway by the Great Lakes Institute.

3) study of clam behaviour with respect to valve closure -
The implications for result interpretation could be serious if the clams are shut-down for two weeks of a three week exposure period. This becomes more important if clams are to be used in comparing discharges for impact assessment.

4) clam size studies -

In order to eliminate sexual differences in uptake of contaminants use of immature clams may be necessary. If the clams are to be used at the same time of year each year, and compared temporally, then the size now used by the Ministry of the Environment can be continued.

5) develop a complement of leech species for biomonitoring -

The literature indicates one species accumulates selected isomers (chlorophenols), so another species or two should be found to serve in monitoring the other isomers.

10.0 RECOMMENDATIONS

1) Concentrate efforts on using clams and leeches as biomonitoring tools (caged) in industrial discharges, STP outfalls, etc.(pinpointing pollutant sources)

2) Obtain an alternate source of *Elliptio complanata* using both Balsam Lake clams and the alternate source in concurrent studies to assess comparability.

3) Obtain a consistent and reliable source for the leech species to be used.

4) Establish a central databank of information on the uses and analytical results from clam and leech studies within the province. This will clarify answers to questions still existing with respect to their use. Baseline data as with the spottail shiner, yellow perch, and *Cladophora* programs will then be available.

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TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Anguilla anguilla Daphnia magna Scardinius erythrophthalamus	artificial ponds				14 months	sediments
Salmo gairdneri Hybopsis gracilis white suckers longnose suckers	caged in field	8/cage 6-11/cage			101 hours	STP
Pimephales promelas Lemna minor Typha sp. Salmo gairdneri	ponds/lab	200/pond			15 weeks	hydraulic fluid vinyl plastic
minnows sport fish	river/lab					industrial discharge
mussels aquatic insects golden eye	river				9 days	blackfly larvicide
planktonic organisms					5 weeks	
Leuciscus rutilus (roach)	field	84 x 20 - 30				runoff
Orconectes virilis (crayfish)	field, lab			wet wt.		
Orconectes virilis	lab (outdoor pools)					lake low pH.

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		PCBs		Larssen,L.
	liver,kidney, muscle ,digestive track	methoxychlor	rainbow trout liver uptake rapid	Lockhart et al 1977
	whole organism	triphenyl phosphate,2-ethyl hexyl-diphenyl phosphate	within 24 hrs only 50% in water	Muir,D.C.G.et al 1982
		trifluralin	proportional to water concentration; river fish slower clearance rates than lab minnows	Spacie et al 1979
	whole organism	methoxychlor	in fish 9 days after treatment; absorbs to suspended particles	Freedeen, G.J.H. et al 1975
	organisms as scraped from multiplates	PCBs	used multiplates,fish and sediments;no consistency	Sloan, R.J. et al 1983
	homogenates of whole organisms pooled.	PCBs	levels peaked in spring no correlation of PCBs, DDT with size, age, sex	Olsson, M. et al 1978
	individual tissues	cadmium ,fenitrothion	final concentration proportional to environmental level, peaked 19 days after application; liver, gill more Cd than-stomach, intestine, tail.	Leonard, S.L., 1979
		pH	early molt stages are most susceptible to low pH; related to Ca uptake.	Malley, D., 1980

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Lampsilis siliquoidea Anodonta grandis	caged in field (monofilament line) (metal pens)	79			10 weeks	STP
Ancylus fluviatilis Mull. (mollusc) Coregonus fera Junine (fish)	lab				24 hours	
Anodonta cataractae (clam)	lab		7 cm.		2 weeks	
Anodonta sp. (mussel)	lab	50	8-10 cm.		24 hours.	
Lampsilis radiata Elliptio complanatus Andonta grandis	field					
Amblema costata Corbicula manilensis Elliptiocrassidens L. claibornesis Megalonaias gigantea Plectromerus dombeyanus Lampsilis anadontoides	field					agriculture
leeches	field/ lab/caging				1 week	

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
none	whole animal	DDT et al; methoxychlor	showed decrease down stream; methoxychlor highest at 6 weeks (lower at 10); A. grandis in later; plateaued in 2 weeks but did not reach as high; invertebrates (Tubif. Chiron) had higher levels but more variable concentration's than mussels.	Bedford, J.W. et al 1968
		atrazine, s-triazine	rapid uptake of atrazine by both, 12-24 hrs.; uptake from water significant, through gills; kinetics - uptake through water-exchange mechanism of uptake and exchange.	Gunkel, G. et al 1980
***** 721 28 days	whole body	fenitrothion	[]'s variable; excreted relatively quickly; conclude OP's do not accumulate to an appreciable amount.	McLeese, D.W. et al 1979
24 hours.		3-trifluoro methyl-4-nitrophenol (TFM)	variable uptake, variable elimination; all concentrated TFM 3-4 x over 24 hours.	Maki, A.W. et al 1980
		fluoroanthene, pyrene, perylene, 1-methyl pyrene, arsenic, tin, radionuclides, mercury, selenium	no correlation between concentration in tissue and body weights; did not seem to accumulate As and Sn; Cd concentrated highest also Hg, Se	Meit, M. et al 1980
		toxaphene, DDT	C. manilensis better able to concentrate pesticides and eliminate them.	Leard, R.L. et al 1980
1 week		2, 3, 4, 6-tetra chlorophenols, PCP, trichlorophenol, chlorophenols	no chlorophenols in water but after 7 days in leeches; no release of CP's; do not appear to degrade CP's; 24 hours BCF 40-100.	Jacob, C. et al 1985

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
fish, leeches, crayfish, tadpoles, benthos, aquatic insects	field					
Glossiphonia complanata H. stagnalis (Helobdella) Erpobdella punctata Dina parva	field					
Dina dubia Glossiphonia complanata, fish (rock bass, white sucker, common shiner, longnose dace, darters),crayfish, bullfrog tadpoles	field					STP, old chemical dump
Limnodrilus hoffmeisteii Tubifex tubifex (oligochaete worms)	lab				110 days	sediments
Gammarus pseudolimnaeus Palaemonetes kadrakensis Orconectes nais Daphnia magna Pternarcys dossata Corydalus cornutus Culex tarsalis Chaoborus punctipennis	lab					
Hyalella azteca	lab			wet wt.		
Procambarus clarkii	field caging				10 days	HCB landfill

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		chlorophenols	fish absorb quickly, eliminate quickly (10 hrs.); leeches high; tadpoles > frogs; aquatic insects, crayfish low.	Carey, J.H. et al 1983
		2, 4, 6-trichlorophenol 2, 3, 4, 6-tetrachloro pherol; PCP	H. stagnalis - highly chlorinated; E. punctata, D. parvus had lower chlorinated; levels in water and leeches did not correspond.	Metcalfe, J.L. et al
2 weeks		2, 4-DCP; 2, 4, 5-TCP, 2, 6-DCP, PCP	leeches accumulated 40,000 - 140,000 x water concentration; rock bass highest fish 3000 x; E. complanata lowest levels; D. dubia best but restricted distribution.	Metcalfe, J.L. et al 1984
48 hour		chlorinated organics	worm uptake proportional to sediment concentration; smaller worms accumulate more.	Oliver, B.G., 1984
		Aroclor 1254	rapid uptake; life changes affected.	Sanders, H.O. et al 1972
		anthracene	uptake from sediments /no sediments from water, rate constant same with/without sediments; organic sed. & anthracene contributed 77% of steady state body burden; animals on organic sediments at highest risk.	Landrum, P.F. et al 1983
some		hexachlorobenzene	males weighed more than females; females tended to accumulate and retain greater proportions.	USEPA 1976

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Orconectes virilis	field caging/lab	6/cage				
Oedogonium cardiacum Daphnia magna Physa sp. Gambusia affinis Ictalurus punctatus	lab				32 days	
Chlorella fuscus (algae)	lab				24 hours	
Salmo gairdneri Perca fluviatilis spike	field/lab (caging & native fish)				4 days (pure dehydro-abietic acid) 2 days (same) 24 hours (linolenic acid)	bleached kraft pulp mill
freshwater fish (various sizes and types)	field	45				

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		fenitrothion	accumulated above environmental levels even after the insecticide had disappeared.	Leonhard, S.L., 1977
		2, 3, 7, 8-tetra chlorodibenzo para-dioxin (TCDD)	accumulates 2-7000 x water concentration; directly related to water ; equilibrium in tissues 7-15 days,not translocated immobile in soil (t 1/2 1 year); slowly photodegraded in soil.	Isensee, A.R., 1978
	living/ dead cells	PCBs	3 diff. PCBs; water concentration increased so did cells; living and dead adsorbed to surface then taken into lipophilic part; accumulation factor 5630, 5420 living, 4760, 5140 for dead cells.	Wang, K. et al
	individual tissues	linolenic acid, dehydroabietic acid, abietic acid; neo -abietic; pimaric; palustric; sandaracopimaric, isopimaric; levopimaric; chloroguaiacols	juvenile RBT - max. 12-24 hrs. declined rapidly, gills > blood, viscera; highest blood plasma; kidney, liver, brain then muscle; 2 days similar; caged RBT plasma bile - after 2 days, no change; individual perch same; pike muscle, liver greater; metabolism - execretion; resin acids excreted via hepatobiliary route in conjugated (detoxified) form; chlorophenols conjugated to glucaronides and sulfates in liver for biliary and branchial excretion; zebrafish - 4 wks. to trichloroveratrole accumulation 80% lost 3 days.	McLeay, D. et al (unpublished 1986)
	muscles, tissues, wastes	organochlorine, insecticides, heavy metals (HCH, DDE DDD, DDT, DDT)	higer levels of OC's in wastes (more fat); primary producers had lower levels, predaceous higher; Hg showed dependent on type of food, other metals did not.	Zamojski, J. et al 1986

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Elliptio complanatus (clams)	field-caging introduced clams	5/cage	6.5 - 7.2 cm.	wet wt.	3 weeks	chemical industry
Spottail shiners (Notropis hudsonius)	field	8-10 x 10 fish/site		wet weight	spring to September	nonpoint sources, industrial, agricultural
Notropis hudsonius (spottail shiners)	field	20 fish composites /site and 10 fish composites /site		wet wt.		nonpoint sources
Elliptio complanata (clam)	field (transplant) in cages	10/cage	6.5-7.2 cm.	wet wt.	4-6 weeks	industrial agriculture
Notropis hudsonius (spottail shiner)	field	10 fish composites	similar sizes each year, the same location mid 30-70 mm.	wet wt.	collected at the same time of year each year	Niagara River industrial, STP
Notropis hudsonius Cladophora glomerata Ellipto complanatus sport fish species	field					Niagara River
Elliptio complanata	field caging		6.5-7.2 cm.	wet wt.		

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	soft body tissues whole	HCB, octachlorostyrene pentachlorobenzene, hexachlorobutadiene, 2, 3, 6-trichloro toluene, alpha-BHC	clams on sediments, did lipid content, no weight loss, determined active inputs.	Kauss, P.B. et al 1985
	whole fish	organochlorine pesticides, PCBs	lipid content, annual collections, nearshore waters Great Lakes; significant site differences as well as temporal differences.	Suns, K. et al 1981
	whole fish composites	octachlorostyrene, HCB, chlorinated phenols, 2,3,7,8-TCDD, poly chlorinated dibenzofurans, trichlorotoluene, chlorobenzene, organochlorines, mercury	lipids, spatial and temporal trends apparent	Suns, K. et al 1985
	soft body tissues	PCBs, organochlorine pesticides.	took up PCBs within 8 days; control clams relatively clean ie. significant differences between the 3 sites.	Curry, C.A. 1978
	whole fish composites	PCBs; mirex; organochlorine pesticides; chlorinated benzenes; 2, 3, 7,8 -TCDD	young fish of a known age and localized area are good indicators of contaminant sources and reflect temporal and spatial differences.	Suns, K. et al 1983
		organochlorine pesticides, PCBs, heavy metals	spottails and clams have proven useful in biomonitoring; Cladophora was useful for OC's and metals; only limited by growth needs ie. wave action essential nutrients.	Report of the Niagara River Toxics Committee, Oct-84
	whole body tissues			Kauss, P.B. et al 1981

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
fish					12 weeks	Grand River
Spottail shiners (Notropis hudsonius)						transboundary migration
Spottail shiners, clams, Morone chrysos (bass) Perca flavescens (y. perch) Ictalurus punctatus (catfish) Cyprinus carpio (carp.)	field caged clams					St. Clair R. chemical industry
spottail shiner Salmo gairdneri (rainbow trout)	field/caging	50 fish/cage				high grade bleach, kraft mill
Perca flavescens Elliptio complanata	field/caging	15 clams/ cage	6.5-7.2 cm.	wet wt.		road oiling
Notropis hudsonius (spottail shiners)	field			wet wt.		Great Lakes industrial, agricultural, nonpoint sources

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
			as fish exposure progressed the # of compounds increased in the fish, therefore identifies classes of compounds of biological significance; fish had more contaminants than did water.	International Environmental Consultants 1981
		mirex, PCBs chlorobenzenes, octachlorostyrene	used to determine transboundary migration of contaminants and point sources for investigation.	Suns, K. et al 1983
		HCB, OCs, dioxins, perchloroethylene, dibenzofurans, pentachlorobenzene, PCBs, hexachloro-butadiene	sport fish denoted decreases over 15 year; clams accumulated HCB, OCs, PCBs, pentachlorobenzene, hexachlorobutadiene; young fish - HCB, OCS, percholoroethylene, dioxins, dibenzofurans; 1, 2, 4-and 1, 3, 5-trichlorobenzene, and 1, 2,3, 5-and 1, 2. 4, 5-tetrachlorobenzene in water not in clams.	St. Clair River Pollution Investigation,1986
	5 whole fish composites	chlorophenols	spottail shiner data pinpointed chlorophenols to be at 1 site.	Flood K. et al 1986
	whole body soft parts; whole fish composites	PCBs	both fish and caged clams had sign levels of PCBs, clams took PCBs up in 8 days.	Suns, K, et al 1980
	whole fish composites	organochlorine pesticides and PCBs	chlordane was higher in urban areas than agricultural; PCBs, total DDT, mirex reductions over time.	Suns et al 1981

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Rana temporaria (frog) Astacus leptodactylus (crayfish)	lab	3 frogs/tank 1 crayfish/ tank		av. 28 +/- 8g.av. 53 +/-13g.		injected phenols
Salmo gairdneri (rainbow trout)	lab				72 hours	
Asiatic clams	field (caged native clams) transplanted	114 clams/ cage	juv.6.5-8.5 mm. adults 21-22.9 mm.			point source discharges thermal
Coregonus artidi (lake cisco) Coregonus clupeaformis (lake whitefish) Salvelinus namaycush (lake trout) Catostomus commersoni (white sucker)Esox lucius (northern pike)	field					

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	gallbladder, gut, gills, antennal, gland; gills, antennial glands	phenol, 3-nitrophenol, 3,5 diethylphenol, 4 - aminophenol	frog routes of excretion - gills, gut, antennal gland, smaller molecular wt. and more polar phenols can be eliminated from compartment 1, eliminated from compartment 2 is reversed except aminophenol; bilary excretion is minor, 4-aminophenol most rapidly eliminated; frog ranks between goldfish and crayfish for excretion of phenol,3-nitrophenol, 3,5-diethylphenol; eliminated phenols by crayfish can not be dealt with the same way, excretion from gills is major route; goldfish can eliminate most rapidly due to high permeability of fish gill.	Nagel R. et al 1981
144 hours		anthracene alone and in mixtures	immature fish were starved - accumulation of contamination in bile, if fish were feeding bile would have been released and metabolites excreted; less anthracene accumulated in mixture than alone; may have been competition for binding sites;higher depuration rates in fish exposed to mixtures - caused by induction of mixed function oxidase enzyme system.	Linder, G. et al 1985
			caged and wild clams behaved similarly; responded as expected along a stress gradient; consider it a good monitor.	Foe, C. et al 1987
		PCBs, DDT, heavy metals	metal level, to water level ratios indicate lake trout and lake whitefish are more suitable for monitoring levels of As and Hg.	Tsui, P.T.P. et al 1981

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Guppies	lab				84 days	
Anodonta cygnea (mussel)	lab	10-12 cm.			3 seasons	
Glyptotendipes barbipes (chironomid larvae)	lab					
Notropis hudsonius (spottail shiners)	field	10 fish composites	similar sizes each year for same location mid 30-70 mm.	wet wt.	collected at the same time of year each year	Detroit R. L. St. Clair L. Erie
Notropis hudsonius (spottail shiners)	field	10 fish composites	similar sizes each year for same location mid 30-70 mm.	wet wt.	collected at the same time of year each year	L. Erie L. St. Clair L. Ontario

TABLE 1 - Freshwater literature on field and laboratory studies using biomonitoring organisms - organics.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		chlorinated biphenyls; hexabromobenzene; octachlorodibenzo-p-dioxin; tetra decachloroterphenyl; dichlorobiphenyl; pentachlorobenzene;	not in live fish but in dead ones; other chemicals the same in both, fast elimination; tetra-hexa-, octa-and deca-chlorobiphenyl showed a gradual increase in exposure then a gradual decrease; clearance of most lipophilic was neg. t 1/2 > 84 days.	Bruggeman, W.A. et al 1984
		lindane, phorate, phosphamidon, trichlorfon	shortening of their active periods in a few days.	Salanka, J. et al 1978
		Aroclor 1242	uptake shows a dose- dependent relationship between substrate concentration and body burden; additional mineral oil - 70-80% reduction inuptake linear - uptake time/body burden no sign. excretion in 1 week,significant accumulation from substrate feeding alone; no equilibrium 0.01 -0.1 ppm.; maybe in lipid stores for last instar stage.	Meier, P.G. et al 1984
	whole fish composites	total chlordane; octachlorostyrene; mercury; PCBs	young fish of a known age and range are good indicators of contaminant sources and reflect temporal and spatial differences; lipid content measured.	Suns, K. et al 1985
	whole fish composites	PCBs organochlorines	young fish of a known age/ range are good indicators of contaminant sources and reflect temporal and spatial differences; lipid content measured.	Suns, K. et al 1978

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Pimephales promelas	caged in field/lab					electroplating factory
Salmo salar	lake	30-40/cage			1 month	
Perca flavescens	field, lab				10 days	sediments
Esox lucius	caged in field	3/cage			3 weeks	
crayfish	caged in field	320 total			55 days	Wabigoon River
Salvelinus namaycush Catostomus commersoni Coregonus clupeaformis Pimephales promelas Semotilus margarita Chrosomus eos Orconectes virilis Lobelia Eriocaulon Potamogeton	field	whole lake			4 months	radium dosed
Esox lucius	lake (transplant)					
2 species of crayfish	lab		various sizes and sexes.			
Orconectes virilis	field					

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	whole body	cadmium	took lab fish 8 days to reach field levels in 12 hours	Sullivan,J.F. 1978
	muscle and liver	mercury		Hasselrot et al 1982 Seelye et al 1982
		mercury,selenium	Se ability to reduce Hg via food chain	Turner,M.A. (?)
	muscle	mercury	fed Hg contaminated food	Canada/Ontario
	whole organism	226 radium	macrophytes reached maximum 20 days fell to stable 3-4 months, crayfish 1 month rose to 370 mBq/g wet wt. some fish like macrophytes,some no relationship to water concentration	Hesslein,R.H. 1984
		mercury	t1/2 2 years	Lockhart, W.L. et al 1972
		mercury	ability to cope with inorganic Hg depends on species, size, sex, external temperature	Heit, M. et al 1977
	individual tissue	copper, cadmium, zinc, lead	can control levels of essential metals; others found at levels in water no significant differences in metals concentration between sexes; gills highest; Pb tends to go to exoskeleton.	Anderson, R.V. et al 1978

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Orconectes virilis	lab		only intermolt crayfish used.			
Elliptio complanata	field				7 days.	Batchawana Bay Bay of Quinte St. Lawrence R. at Maitland.
Lampsilis ventricosa (pocketbook mussel)	caged in field	36	similar		2, 4, 8, 12 weeks	mining
Elliptio complanata Margaritifera margaritifera Anodonta anatina	field					
Anodonta cygnea	lab			dry wt.	20 weeks.	
Anodonta cyonea Anodonte anatina Unio pictorum	lab				22 weeks.	

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	whole animal, individual tissues	cadmium	highest in gills and muscle; body size, sex had no effect; whole animal concentration linear relationship to exposure concentration's; increased sensitivity with time.	Mirenda, R.J., 1986
	shells, soft tissues.	lead,copper,nickel, zinc	Zn - soft tissues Pb - whole shell Cu, Ni equilibrium in tissues/shell Cu, Zn do not reflect environment levels; high Fe can bind inorganic metal forms (Cu, Zn, Pb) so unavailable.	Dermott, R.M. et al (unpublished manuscript)
3 days	whole soft tissues.	lead,cadmium	do not feel equilibrium was reached, after 12 weeks only 1 mussel alive in each of 3 stations.	Czarnezki, J.M., 1987
	shells	cadmium,copper, lead,manganese	no sex differences in shell metal uptake; will stop growing; Elliptio migrate if water > 24 degrees C.; Cd shell 100 x concentration soft; Cu 6 x concentration; Pb 450 x concentration; Mn 1 x concentration; Cu concentrated in shell 24 x than in fish.	Imlay, M.J., 1982
	whole animal an separate organs.	cadmium	in gills > labial palps > mantle > guts/gonads > foot; 5ppb - linear over 20 wks. 25 ppb - biphasic, slow linear for 4 weeks, no change 4-6, rapid after, to 10 weeks; limited value as monitor.	Hemelraad, J., 1986
	whole animal an separate organs.	cadmium	accumulated in whole animal as well as tissues in non-linear way; for whole burden 3 species =; species differences in individual organs, some larger.	Hemelraad, J., 1986

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Anodonta anatina	lab	50 animals/ 40 L tank			7 months	
Corbicula fluminea (Asiatic clam)	lab (river water flowthrough)				4 weeks	
Physa integra (gastropods) Pseudosuccinea columella Helisoma trivolis Idiopoma malleata Campeloma decisium (prosobrach) Brasenia sp. (macrophytes) Utricularia sp. Calomba sp. Myriophyllum sp.	field					sediments
Quadrula quadrula (mussel)	field / lab	16/cage			45 days	copper electro-plating.
Elliptio complanata	field					sediments
Anodonta nuttalliana Lea	lab	1/tank				

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	individual tissue	di-n butyltin dichloride at 15 ppb tin not lethal then bis (tri-n-butyltin) oxide at 5 ppb tin	highest concentration in kidney; different distribution than Cd; compound is eliminated at a faster rate than inorganic Cd.	Holwerda, D.A. et al 1986
		copper,zinc	Cu steady state NOT in 28 days; Zn showed relative increase; Zn can be regulated; quantitative biomonitoring of Zn may be impossible.	Graney, R.L. Jr. et al 1983
		lead	molluscs, macrophytes reflected differences in Pb levels; aufwuchs did not; concentration in snails correlated to dissolved Pb in water rather than aufwuchs or plants; C. decisum lowest levels although it burrows; dietary Pb may be important but dissolved more significant.	Newman, M.C. et al 1982
none		copper	Cu inversely related to body weight (small clams, large amounts).	Foster, R.B. et al 1978
	whole body	trace metals	highest levels in gills, lowest in foot; tried to relate body levels to sediment fractions, related to fractions of total metal load, and competitive effect of sediment parts eg. amorphous iron oxyhydroxides.	Tessier, A. et al 1984
	soft tissues (individual)	scandium,chromium, manganese,iron, zinc,europium,lead, tantalum,mercury cobalt	valence state determined distribution; Sc, Cr, Fe, Eu, Ta, Hg, higher % in organs (digestive) others higher in calcareous tissues.	Harrison, F.L. et al 1972

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
6 species of clam	field					urban, agriculture
Elliptio complanata Alasmidonta undulata Anodonta implicata	field					goldmining
Dreissena polymorpha (mussel)	field caging		15 - 20 mm.		40 - 60 days	
tubificids, clams, fish	field					sediments
Corbicula manillensis (Asiatic clam)	field					
Elliptio complanata Andonta grandis Lampsilis radiata	field		6	dry weight		
Anodonta anatina (mussel)	field	immature		dry wt.		industrial rural, STP outfall

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	shell, soft tissues.	cadmium,copper,lead zinc	shell Cd < Cu < Zn < Pb; body Cd < Cu < Pb reflected concentration's in sediments; shell lower; highest in gills >viscera > muscle > shell; Zn plays physiological role.	Anderson, R.V.
	soft tissues	mercury,arsenic,	E. complanata found high levels of Hg and As; but poor regulator of Hg soft tissue concentration's increased exponentially with body wt. and age increase; high correlation, wt./ age.	Metcalfe, J.L.
		copper	uptake in last 3 weeks of exposure; low exposure low uptake and vice versa.	del Castelho, P., et al 1983
		copper,nickel,lead chromium,lithium, cobalt,cadmium	tubificids/clams close to sediments; worms, clams, fish for Cu, Ni, Pb, Cr, Li, Co, Cd, Zn highest in clams, worms, fish.	Mathis, B.J. 1973
	shells	lead	adsorbs to surface of empty shells; significant difference in half shells; statistically significant difference in Pb from shells from different areas (pH)	Clarke, J.H. et al 1976
	soft tissues	trace metals	believe trace metal enrichment is a 2 step mechanism (1) prior preconcentration into particulate matter (2) ingestion; recommend as a long-term insitu monitor.	Lord, D.A. et al 1975
	individual tissues	zinc,nickel,lead, cadmium,copper, mercury	mantle, kidneys, ctenidia had highest levels; metals high - correlation between concentration /body wt.; positive polyvalent ions Zn ,Cu*, Hg*concentrated on mucous sheets; dry body wt/age linear line.	Manly, R. et al 1977

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Anodonta grandis Lampsilis radiata Lasmigona complanata	field/lab				1 week	lake Hg contaminated
Physa gyrina (snail)	field		immature			
Macrobrachium rosenbergii (prawns)	lab	2000	6-9 cm		50 days	contaminated sediments
Corbicula fluminea (clams)			5 cm.		48 days	
carp, common sucker, channel catfish, RBT, brown trout, lake trout, largemouth bass, crappie, bluegill, walleye					monitoring program	
Valvata piscinalis Lymnaea peregra (snails) macrophytes, aufwuchs, fish	field/lab					mining
Mysis relicta	field					sediments
Ephemerella grandis (mayfly)	lab/field (liveboxes)				49 hours then every 24 hrs. taken	polluted stream
aquatic insects	lab/field					

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	whole body	mercury	rate of uptake with increasing Hg; must be severely polluted before uptake; significance difference among species; slower release after exposure; felt wt. loss could increase Hg concentration	Smith, A.L. et al 1975
		cadmium	rapid uptake	Weir, C.F. et al 1976
		PCBs,mercury,lead, cadmium	both accumulated PCB's; prawns turned up sediment so Hg available; clams no Cd some Pb from sediments	Tatem, H.E., 1986
		cadmium,lead, arsenic,selenium mercury		May, T.W. et at 1981
24 hours	whole Valvata separate organs of snail	lead	eels ate snails, similar to snails but lower; shell incorporated Pb; foot lost slower than digestive; gut walls and disgestive gland seemed to regulate Pb intake.	Everard, M. et al 1984
		lead	suggest Mysis take Pb from sediments migrate upward, release it as fecal matter which settles out or is eaten by others.	Evans, R.D. et al 1983
		zinc	field paralled lab; insects accumulated heavy metals in relationship proportional to concentrate in water	Nehring, R.B.
		cobalt,chromium, antimony,scandium, iron,potassium, manganese,sodium	52% of body burden Cr in gut contents; for 5 metals as animal larger concentration smaller; using regression of metal concentration on dry wt. gives > correlation than using length.	Smock, L.A. 1983

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
fish	field enclosures					
Limnodrilus hoffmeisteii Tubifex tubifex chironomids amnocoeles (lamprey)	lab					
Scenedesmus obliquus	lab					
Hydropsyche sp. Chironomus	lab				achieved equilibrium 3-5 days after initial exposure.	
Physa integra Campeloma decisum (gastropods)	lab		3.6-8.1 5-33 mm.	0.0007- 0.0070 g. 0.0046- 0.2775 g. dry weight		
Asellus communis (isopod)	lab					different pH levels

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		mercury	when sediments absent Hg bioaccumulates 8-16 x faster than when suspended or on bottom; resuspension aids in removal of bioavailable Hg and Zn.	Rudd, V. et al 1983
48 hours for some, not useful for tubificids (coprophagic)	gut contents, whole animal	metals	gut sediment metal load a high % of total body burden.	Chapman, P.M. 1985
		cadmium	rapidly growing young cultures accumulated less than older cultures approaching stationary growth phase.	Cain, J.R., 1980
		cadmium, nitriletri acetic acid (NTA) (chelator)	both free and bound Cd accumulated by Hydrospyche; other work - complexation of Cd to other organic ligands reduced uptake by Chironomus; even dead organisms accumulate Cd.	Dressing S.A., et al 1982
4 weeks eliminated rapidly first 4 days, then slow		lead	P. integra concentration independent of size, C. decisum smaller animals had higher Pb; no significant change in gravid and non-C.decisum after 3-4 weeks in clean water; some Pb is strongly bound.	Newman, M.C. et al 1983
		zinc,lead	Zn regulated, therefore, not different at any pH level; Pb accumulationsignificant at pH 5.5 and 4.5; at 5.5 rate of uptake > from sediment than water; Pb associated with amorphous iron oxides which undergo dissociation at lower pH.	Lewis, T.E. and A.W. McIntosh, 1986

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Daphnia magna	lab					pH
Zooplankton	lab					pH
Sparangium sp. (bur reed) Utricularia vulgaris (bladderwort) Myriophyllum exalbescens (water milfoil) Nuphar variegatum (water lily) Calla pallustris (water drum)	field					metal smelter
Sphaerotilus (bacterium) tubificids, plants, eels	lab/field					treated sewage wool scouring and dyeing
aufwuchs	field	3 slides/ month/site			2 months	New Jersey reservoir
filamentous algae	field (artificial subtrates)					soft water lakes

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		aluminum	maximum Al toxicity and bioaccumulation pH 6.5 (0.32 mg. Al/L); 24 hrs bioconcentration ratio 10,000 at pH 6.5, 4000 pH 5.0, neg. pH 4,5.	Havas, M., 1985
		zinc,cadmium	Zn supresses Cd bioaccumulation Zn can reduce population numbers at levels below toxicity for zooplankton;combined effects of Zn and Cd due to Zn.	Marshall, J.S. et al 1983
	leaves, stems, roots	metals	surface area to volume relationship was important; fleshy heavily rooted plants about 1/5 metal concentration; Myriophyllum a good indicator species;no correlation of plant metal concentration to environment levels; 2 unrelated conditions affected plant metal concentration (1)amount of deposition (2) Ca concentration of l ake water can not rely on macrophytes to distinguish grades of contaminants or where it is ie. sediments, water, fallout.	Franzin, W.G. et al, 1980
		metals	lab and field cultures had high concentration metals; tubificids, plants, eels elevated; tubificids eat bacterium; different bacterial strains can concentrate metals to levels, later in growth cycle.	Patrick, F.M., et al 1970
		lead,zinc	rust-coloured matrix contained more Pb and Zn per unit area than microflora; NOT a reliable biomonitor.	Newman, M.C., et al 1983
		copper,nickel,metals	1000 - 10,000 fold increase in concentration over water; Cu, N. clear pattern - reflects quantitative dissolved metals or water pH, not so other metals, SHOWS PROMISE - easier to get a clear sample of good quantity.	Bailey, R.C. et al 1985

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Anabaena, Ankistrodesmus braunii, Chlamydomonas	lab			dry wt.		
Fritschiella tuberosa (filamentous green)	lab/field caging	"appropriate amount of algae with distilled water"			24 hours	
Spirogyra Zygogonium ,Mougeotia Microspora (filamentous algae)	field					
Chlorella pyrenoidosa	lab					
Lemanea (red alga)	field (transplants made in river, attached to boulders)				4-5 months length of growing year	mining
Lepomis cyanellus (green sunfish)	lab		mean 13 +/- 2 cm.	mean 36 +/- 13 g.	0, 2, 4, 6 days	
Orconectes virilis (crayfish)	field					

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		cadmium,copper	Anabaena accumulated Cd equilibrium in 12-24 hours; not as good with Cu.	Laube, V. et al 1979
		heavy metals	grown in lab with known metal load; particulate scan accumulate in chamber, planktons filtered; IT WORKS.	Ahlf, W. et al 1981
		metals (lead,zinc)	metal concentration several orders of magnitude > ambient; iron levels seemed to plateau when water concentration 1mg/ml; Zn seems to be regulated	Foster, P.L. 1982
	live, dead cells	cadmium	pH dependent but concentration proportional to water no accumulation in dark or dead cells; pH 7 accumulates 2x pH 8; Mn and Fe can block Cd accumulation (compete for transport sites).	Hart, B.A. et al 1977
		zinc,cadmium,lead	found only in fast flowing rivers, rare in eutrophic waters, therefore, restricted use although they feel a good tool; high Ca, Mn - decreased Zn uptake; Zn reflected levels in native filaments when moved.	Harding, J.P.C. et al 1981
	gall bladder, bile spleen, gill, ovaries, testes	arsenic (as sodium arsenate)	exposed to As 60ppm; gall bladder, bile higher concentration in 6 days 35-78-159 ppm; spleen is storage site; decrease in gill over 6 days; ovaries, testes did not accumulate As.	Sorenson, E.M. et al 1979
		trace metals lead, copper,manganese, cadmium, zinc	hepatopancreas regulates Zn; Cu related to hemocyanin; Cd highest in gills Pb also in gills related to adsorption; Pb could be absorbed to exoskeleton.	Anderson, R.V. et al 1978

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Chironomus riparius	lab					
Orconectes virilis Stizostedion vitreum (walleye)	field		65 mm.			contaminated pulp & paper chlor alkalai
crayfish pike (young, adults) yellow perch	field/caging	8 fish comp. (perch) individual pike, crayfish			55 days (crayfish)	contaminated pulp & paper mill sediments
Perca flavescens (yellow perch)	field	comp. 8/ site				acid rain
Ulothrix Cladophora (submerged) Cladophora (fringing) Bangia (all filamentous algae)	field					non point source
Anodonta grandis Stizostedion vitreum vitreum(walleye)	field/caging of indigenous clams	20/cage			2 months	gold mining

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	larvae, pupal exuviae, adults	mercury	larvae BCF 12,600 exuviae 12,470 with respect to water adults only 29% of larvae (they can eliminate it)	Rossaro, B., et al 1986
		mercury	levels indicates time lag as Hg decreased so did fish levels; walleye show an exponential decline.	Parks, J.W. et al 1980
	whole animals (perch,crayfish) fish fillets	mercury	young pike seemed least suitable, perch, crayfish good indicators easier to catch, statistically significant relationship between Hg concentration and animals despite feeding, habitat,metabolism, accumulation pathways.	Parks, J.W. et al 1980
	whole animal	mercury	significant correlation between Hg in fish, pH aluminum, no correlation, Hg/wts. Hg/lengths, Hg/lipids; drainage area/lake volume ratio and Hg concentration in fish - strong correlation.	Suns, K. et al 1980
	whole plant mask	heavy metals	relative concentrations in both Ulothrix & Cladophora is similar N, Ca > Al,Fe, Mg, P> Mn > Zn > Pb, Cu >As, Cr, Ni > Co > Cd, Se > Sb > Hg; take up elements in prop. to levels in the water; LOI flags samples with high inorganic content and, therefore,less bioavailability, filaments may be coated with suspended sediments , metals are higher in soft water.	Jacksn, M.B., 1985
	fish muscle whole clam tissue		most clams died over the study period.	Parks, J.W. et al 1982

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Najas quadalupensis (macrophytes) crayfish					(crayfish)	
Drunella D. grandis (mayflies)	field caging				24, 48, 72 hours	
Lepomis macrochirus (bluegill) Micropterus salmoides (largemouth bass)	lab					
Amblema perplicata (three-ridge clam)	field (caging)	6/cage		wet and dry weights	1 week	industrial sources, electro-plating
Pimephales promelas (fathead minnows)	lab					coalburning electric power generating plants.

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		lead	roots took Pb from sediments but no translocation; 4 x > Pb in those exposed to sediments; smaller had more concentration; concentrated in exoskeleton;senescent macrophytes have higher Pb (adsorbed).	Knowlton, M.F. et al 1983
		cadmium,molybdenum	concentration Mo, Cd even when water level low; mayflies more than caddisflies; dead and alive similar, therefore not physiological; dynamics of the 2 are different.	Colborn, T. 1982
		cadmium	wt. gains; accumulation >/- water concentration;increase with time; equilibrium after 2 months; bass internal tissues highest then gills - rest; bass more sensitive; site of damage nervous system.	Cearley, J.E. et al
none		zinc,cadmium	highest mean concentration Zn gills of clams; highest mean concentration Cd digestive gland;gills act as filtering mechanism for food, particulate matter respiration; digestive gland also an adsort/ absorb process; small particles are taken into gland by phagocytosis or pinocytosis -Cd mediated by a carrier system bound to Ca or Mg granules -storage in digestive gland.	Adams, T.G. et al 1981
		selenium	health okay, gained wt.; all fish in a group gained the same rate per unit fish wt.; heavier fish had more Se; difference in uptake	

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Pimephales promelas (fathead minnows)	lab					coalburning electric power generating plants.
Fish (freshwater)	lab				2 days, 4 days	bacteria containing heavy metals

TABLE 2 - Freshwater literature on field and laboratory studies using biomonitoring organisms - metals.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		selenium	kinetics between Se in food and water - 2 functional compartments; inorganic unbound Se (depuration rate rapid) organic bound (rate of loss dependent on cellular metabolism) selenite and selenate bio concentration from water 2- 30 x; ability to accumulate Se from food related to concentrate in diet; do not bioconcentration levels higher than in food.	
		heavy metals	bacteria containing heavy metals were fed to tubificids then those fed to fish; after 2 days a significant increase in fish.	Patricia F.M. et al 1978

TABLE 3 - Specific contaminants - biomonitoring organism, exposure, accumulation, and time to equilibration

Freshwater Organisms

CONTAMINANT	GROUP OF ORGANISMS	EXPOSURE/ ACCUMULATION	EQUILIBRIUM	COMMENTS
cadmium	phytoplankton	72 hours/72 hours	12-24 hours	
	aquatic insects	72 hours	72 hours (mayflies) 3-5 days (caddisflies)	mayflies are preferred
	crustaceans (crayfish)			study exposure periods are influenced by molting periods
	molluscs (bivalves)			
	Asiatic clam	4 weeks	11 days	high bioconcentration factor make it a useful organism
	pocketbook clam	40-60 days/ 12 weeks	none	did not reach equilibrium; species differences in cadmium uptake is biphasic; whole body levels are similar, individual organs are species specific
	fish (fathead minnows)		12 hours (field) 8 days (lab)	stress in the field due to higher temperatures and turbidity increased metabolism and uptake
	fish (yellow perch)	birth to capture (15 months)		yearling fish
	fish (spottail shiner)	birth to capture (5 months)		young of the year fish
copper	molluscs (bivalves) Quadrula quadrula	45 days/14 days	none	

TABLE 3 - Specific contaminants - biomonitoring organism, exposure, accumulation, and time to equilibration

Freshwater Organisms

CONTAMINANT	GROUP OF ORGANISMS	EXPOSURE/ ACCUMULATION	EQUILIBRIUM	COMMENTS
lead	macrophytes			accumulated in roots
	crustaceans (isopod) Asellus communis			accumulation is pH dependent; depending on pH uptake can be from sediments or water
	crustaceans (crayfish)			lead concentrated in exoskeleton lost at molt; accumulation greater by small crayfish and those on contaminated sediments
	molluscs (gastropods)			levels correlated to dissolved lead in water rather than sediments; also related to levels in macrophyte which they feed on; species differences on accumulation rate, concentration and depuration
	(bivalves)	12 weeks/2 weeks	none reached	depuration 3 days; showed temporal and spatial trends; concentration factor 175 over background
	fish (spottail shiners)			changes in organic lead levels in water are reflected rapidly in the fish
zinc	aquatic insects (mayflies)	49 hours		concentrated in relative proportion to water concentration

TABLE 3 - Specific contaminants - biomonitoring organism, exposure, accumulation, and time to equilibration

Freshwater Organisms

CONTAMINANT	GROUP OF ORGANISMS	EXPOSURE/ ACCUMULATION	EQUILIBRIUM	COMMENTS
mercury	aquatic insects (Chironomus riparius)			bioconcentration factor from water 12,600, exuvia 12,470; adult only 29% of larvae indicates loss of mercury through molting of exoskeleton
	crustaceans (crayfish)			crayfish size; organic content of sediments; mercury species; molt stage; determine mercury concentration
	molluscs (bivalves)	6 weeks/no accumulation		in a contaminated system no mercury found in clams but in another contaminated system indigenous clams had high levels
	fish (pike)	3 weeks		selenium reduced mercury uptake
PCBs	phytoplankton	24 hours		dead and living cells had similar concentrations
	zooplankton (D.magna)			accumulated PCBs from sediments
	molluscs (bivalves)	29 days/8 days		reflected water and fish levels
chlorophenols	leeches	24 hours		no release after one week; species differences in accumulation

TABLE 3 - Specific contaminants - biomonitoring organism, exposure, accumulation, and time to equilibration

Freshwater Organisms

CONTAMINANT	GROUP OF ORGANISMS	EXPOSURE/ ACCUMULATION	EQUILIBRIUM	COMMENTS
miscellaneous organic contaminants	phytoplankton, zooplankton, snails, fish	32 days	7-15 days	accumulated to different levels (2,3,7,8-TCDD)
	fish (spottail shiners)			accumulate 2,3,7,8-TCDD, polychlorinated dibenzofurans, trichlorotoluene, chlorobenzene, HCB, octachlorostyrene

TABLE 4 - Summary of organisms and problems associated with use as biomonitors.

ORGANISM	CONTAMINANT REGULATED	CONTAMINANT LOSS	INTERFERENCES	COMMENTS
phytoplankton			pH affects growth rate and uptake;Mn,Fe,EDTA block Cd uptake	small size increases need for large quantities for adequate analytical samples; living and dead cell accumulation.
filamentous algae	zinc, iron, manganese	decomposition of plant		restricted to specific areas of growth eg.Cladophora, wave, wind action, and rock shoreline.
zooplankton	zinc	defecation	Zn suppresses Cd accumulation	sensitive to metals.
macrophytes		lead released after plant die-off		accumulate in roots;surface area/volume relationship with uptake;not found in many areas to be assessed by environmental programs.
aquatic insects		exoskeleton-mercury		accumulation by dead and living organisms;life stage changes affect use as biomonitors.
crayfish	copper, zinc	exoskeleton-cadmium, nickel, mercury	lead associated with amorphous iron oxides; pH affects contaminant uptake	the presence and organic content of sediments affect contaminant uptake; sensitive to contaminants during molt;cannibalistic.
worms				sediment organic content can affect availability and uptake of contaminants.
leeches				do not appear to accumulate organochlorines.
molluscs (gastropods)				lead associated with sediments or plants not water;shell incorporates lead;some species size determines accumulation; sensitive to cadmium.

TABLE 4 - Summary of organisms and problems associated with use as biomonitors.

ORGANISM	CONTAMINANT REGULATED	CONTAMINANT LOSS	INTERFERENCES	COMMENTS
(bivalves)	zinc, copper		high iron levels in water can bind inorganic metal forms onto hydrous iron oxides making them biologically unavailable; Cd with EDTA, NTA, humic acid decrease accumulation	Zn, Cu, Hg ions concentrate on mucous sheets and are therefore not assimilated within tissues;some metals equilibrium not reached even after 3 months;Cd has a biphasic accumulation above a certain level;Hg accumulated in highly contaminated system over a long period;Cu inversely related to body weight.
fish	zinc, copper	excretion	selenium in water reduces mercury accumulation	excrete chlorophenols rapidly;react to changes in organic lead quickly; fish movement difficult to pinpoint sources unless fish are caged;seasonal variation in weights,lipids, contaminants;PAHs excreted rapidly.

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
Aroclor 1242	6. barbipes			wet wt.
1,2 - DCB (1,2-dichlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184 g.
			9.5 +/- 1.5	283 +/- 76 g
			10.5 +/- 1.5	419 +/- 101g
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
			7.2 +/- 1.5	279 +/- 31
			9.4 +/- 2.9	277 +/- 58
			8.7 +/- 1.2	400 +/- 130
1,3 - DCB (1,3-dichlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 76
			10.5 +/- 1.5	419 +/- 101
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
			7.2 +/- 1.5	279 +/- 31
			9.4 +/- 2.9	277 +/- 58
			8.7 +/- 1.2	400 +/- 130
1,4 - DCB (1,4-dichlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 76
			10.5 +/- 1.5	419 +/- 101
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
1,3,5 - TCB (1,3,5-trichlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 76
			10.5 +/- 1.5	419 +/- 101

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
	30 days			Meier, P.G. et
Substrate 0.01 ppm	0% oil 0.75 ug/g			al, 1984
		0.25% oil 0.15 mg/g		
		1.0% oil 0.10 mg/g		
0.1 ppm	13.2 ug/g	3.5% oil 2.0 mg/g		
1.0 ppm	19.5 ug/g	5.4% oil 2.9 mg/g		
Water 9 +/- 6 ng/L	0 day	Fish ND	2 fish per	Oliver B.G. et
	34 days	(control) 3.2 +/- 0.5	exposure	al, 1983
	119 days	2.9 +/- 1.5	period.	
47 +/- 17 ng/L	8 days	14 +/- 2.3		
	69 days	12 +/- 3.8		
	119 days	14 +/- 1.8		
940 +/- 160 ng./L	7 days	390 +/- 66		
	43 days	630 +/- 190		
	105 days	670 +/- 190		
4 +/- 2 ng/L	0 day	ND		
	34 days	6.7 +/- 0.7		
	119 days	ND		
28 +/- 5 ng/L	8 days	14 +/- 2.3		
	69 days	12 +/- 4.2		
	119 days	13 +/- 2.2		
690 +/- 150 ng/L	7 days	360 +/- 57		
	43 days	600 +/- 190		
	105 days	640 +/- 100		
Water 4 +/- 3 ng/L	0 days	Fish ND		
	34 days	2.8 +/- 1.0		
	119 days	ND		
28 +/- 5 ng/L	8 days	12 +/- 2.0		
	69 days	11 +/- 4.8		
	119 days	9.9 +/- 3.0		
0.3 +/- 0.1	0 day	ND		
	34 days	1.1 +/- 0.3		
	119 days	0.2 +/- 0.1		

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
1,3,5 - TCB	Salmo gairdneri		8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
1,2,4 - TCB (1,2,4-trichlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 76
			10.5 +/- 1.5	419 +/- 101
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
1,2,3 - TCB (1,2,3-trichlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 67
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
1,2,4,5 - TeCB (1,2,4,5-tetrachloro-benzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 67
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
1,2,3,4 - TeCB (1,2,3,4 tetrachloro-benzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 67
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
QCB (pentachlorobenzene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 69
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
			7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 69

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
2.3 +/- 0.4	8 days	3.7 +/- 0.7		Oliver B.G. et
	69 days	4.4 +/- 1.3		al, 1983
	119 days	4.5 +/- 0.7		
0.5 +/- 0.2	0 days	0.22 +/- 0.06		
	34 days	4.7 +/- 0.7		
	119 days	0.3 +/- 0.1		
3.2 +/- 2	8 days	4.0 +/- 0.8		
	69 days	4.6 +/- 1.5		
	119 days	4.4 +/- 0.8		
0.7 +/- 0.3	0 day	ND		
	34 days	2.2 +/- 0.4		
	119 days	0.1 +/- 0.04		
4.3 +/- 2	8 days	4.8 +/- 0.8		
	69 days	5.3 +/- 1.6		
	119 days	5.3 +/- 0.8		
0.2 +/- 0.2	0 day	0.7 +/- 0.7		
	34 days	1.6 +/- 0.4		
	119 days	0.6 +/- 0.3		
1.0 +/- 0.5	8 days	2.6 +/- 0.5		
	69 days	5.7 +/- 1.5		
	119 days	6.9 +/- 1.0		
0.3 +/- 0.2	0 day	0.23 +/- 0.7		
	34 days	1.8 +/- 0.4		
	119 days	1.0 +/- 0.4		
1.4 +/- 0.3	8 days	2.8 +/- 0.6		
	69 days	7.7 +/- 2.0		
	119 days	7.6 +/- 1.0		
0.1 +/- 0.1	0 day	0.46 +/- 0.18		
	34 days	1.5 +/- 0.2		
	119 days	0.9 +/- 0.4		
0.34 +/- 0.1	8 days	1.2 +/- 0.2		
	69 days	4.1 +/- 0.7		
	119 days	5.2 +/- 0.5		
0.1 +/- 0.1	0 day	2.3 +/- 0.2		
	34 days	3.4 +/- 0.2		
	119 days	2.7 +/- 0.9		

TABLE 5 - Examples of freshwater biomonitoring exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
HCB (hexachlorobenzene)	Salmo gairdneri		8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
HCBD (1,1,2,3,4,4-hexachloro-1,2-butadiene)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 69
			8.1 +/- 1.7	242 +/- 27
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
HCE (hexachloroethane)	Salmo gairdneri		7.1 +/- 0.7	255 +/- 184
			9.5 +/- 1.5	283 +/- 62
			10.5 +/- 1.5	349 +/- 69
			8.1 +/- 1.7	242 +/- 184
			8.7 +/- 2.5	285 +/- 62
			8.2 +/- 1.9	349 +/- 67
Mercury	Chironomus riparius			
2,3,4-trichlorophenol 2,4,5-trichlorophenol 2,4,6-trichlorophenol 2,3,4,5-trichlorophenol 2,3,5,6-trichlorophenol pentachlorophenol	Salmo gairdneri (rainbow trout)			
3-trifluromethyl - 4-nitrophenol (TFM)	Anodonta (sp.)			

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
0.32 +/- 0.3	8 days	2.9 +/- 0.4		
	69 days	4.5 +/- 0.8		
	119 days	6.0 +/- 0.5		
0.03 +/- 0.01	0 day	0.09 +/- 0.05		
	34 days	0.2 +/- 0.05		
	119 days	0.08 +/- 0.02		
0.10 +/- 0.02	8 days	0.37 +/- 0.09		
	69 days	0.59 +/- 0.19		
	119 days	0.76 +/- 0.14		
0.03 +/- 0.01	0 day	0.06 +/- 0.04		
	34 days	0.06 +/- 0.01		
	119 days	0.06 +/- 0.04		
0.32 +/- 0.08	8 days	0.26 +/- 0.06		
	69 days	0.20 +/- 0.08		
	119 days	0.28 +/- 0.07		
mean control 0.23 ppb mean treated 5.50 ppb	29 days	4.20 Larvae (ppm) 69.35 Larvae 19.54 Pupal exuviae 57.61 ppm/fresh wt. 7.76 Adults 19.93 Adults		Rossaro B. et al, 1986
Effluent ng/L (5 days mean)		fish 3 composites samples	cage location not directly at effluent outfall.	Flood, K. et al, 1986
11650 +/- 3472		118,176 ng/g ,ND		
1260 +/- 671				
8.68 mg/l solution	1 hour 2.5 hours 10 hours 14 hours	Foot -(D)* (W)* 	18.1 3.2 79.3 11.8 66.4 12.4 209.2 36.6	Maki, A.W. et al, 19___.

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with lime-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
3-trifluromethyl - 4-nitrophenol (TFM)	Anodonta (sp.)			
2,3,7,8-tetra chlorodibenzo-para-dioxin				

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
		Gill - 34.9		Maki, A.W. et
		6.4		al, 19__.
		93.9		
		9.3		
		98.2		
		13		
		108.9		
		32.5		
		Viscera - 18.4		
		1.9		
		96.6		
		15.8		
		78.1		
		11.2		
		185.4		
		26.7		
		Algae:	standard error	Isensee, A.R. et
Water ppt	1 day	1.30 +/- 0.70 ppb	of means for	al, 1978
3.44 ppt	3 days	2.95 +/- 0.84 ppb	3 replicates	
2.93 ppt	7 days	5.02 +/- 0.47 ppb		
2.42 ppt	15 days	1.71 +/- 0.93 ppb	Algae	
2.58 ppt	32 days	4.25 +/- 1.16 pbb	(Oedogonium	
4.15 ppt		Snails:	cardiacum)	
		2.48 +/- 0.41	Snails	
		3.62 +/- 0.21	(Physa sp.)	
		5.07 +/- 0.58	Daphnids	
		9.74 +/- 1.07	(Daphnia magna)	
		5.75 +/- 0.94	Mosquito fish	
		Daphnids:	(Gambusia affinis)	
		6.81 +/- 0.48	Channel Catfish	
		12.16 +/- 0.78	(Ictalurus	
		17.11 +/- 5.77	punctatus)	
		8.58 +/- 1.18		
		7.43 +/- 1.34		
		Mosquito fish:		
		2.30 +/- 1.29		
		4.85 +/- 1.27		
		11.74 +/- 2.40		
		6.72 +/- 0.65		
		ND		

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
lead	Mysis relicta			7.7 mg dry wt.
				9.0 mg
				5.2 mg
				5.7 mg
				10.8 mg
				8.3 mg
				2.0 mg
				13.3 mg
2,6 - DCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g
2,4 - DCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g
3,4 - DCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g
2,4,6 - TCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g
2,4,5 -TCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g
2,3,4,6-TTCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g
2,3,4,6 - TTCP	leeches (combined)			2.40 g wet
	rock bass			25.66 g
	crayfish			19.58 g
	bullfrog tadpole			3.80 g

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
2.9 mg/g dry wt.		sediments 35 mg/g dry		Evans, R.D. et al, 1983
6.2 mg/g		350 mg/g		
11.9 mg/g		750 mg/g		
13.7 mg/g		750 mg/g		
1.5 mg/g		20 mg/g		
8.5 mg/g		160 mg/g		
13.5 mg/g		750 mg/g		
3.1 mg/g		75 mg/g		
water 0.082		5350 ng/g	ng/g wet wt/ ug/L water water - result of 4 samples collected May, July, September, November.	Metcalfe, J.L et al, 1984
		258 ng/g		
		292 ng/g		
		84 ng/g		
water 0.306		12267 ng/g		
		116 ng/g		
		5 ng/g		
		nondetectable		
water 0.133		6064 ng/g		
		nondetectable		
		1 ng/g		
		nondetectable		
water 0.194		13588 ng/g		
		7 ng/g		
		10 ng/g		
		10 ng/g		
water 0.087		11883 ng/g		
		48 ng/g		
		3 ng/g		
		31 ng/g		
water 0.020		1380 ng/g		
		9 ng/g		
		5 ng/g		
		nondetectable		
water 0.036		2671 ng/g		
		10 ng/g		
		1 ng/g		
		19 ng/g		

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
1,2 - DCB	Helobdella stagnalis			0.147 g wet
	Glossiphonia complanata			1.147 g
1,2,3 - TCB	Helobdella stagnalis			0.147 g wet
	Glossiphonia complanata			1.147 g
1,2,3,4 - TTCB	Helobdella stagnalis			0.147 g wet
	Glossiphonia complanata			1.147 g
HCB	Helobdella stagnalis			0.147 g wet
	Glossiphonia complanata			1.147 g
pp DDT	Helobdella stagnalis			0.147 g wet
	Glossiphonia complanata			1.147 g
As	Oligochaeta			
	Chaoborus			
	Chironomus			
	Helisoma sp.			
	Hydropsychidae			
	A. cataracta (small)			
	A. cataracta (med.)			
	A. cataracta (very lrg.)			
Hg	Oligochaeta			
	Chaoborus sp.			
	Chironomus sp.			
	Helisoma sp.			
	Hydropsychidae			
	A. cataracta (small)			
	A. cataracta (med.)			
	A. cataracta (very lrg.)			
EHDPP	Duckweed			

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
water 0.070 ug/l		nondetectable nondetectable	one site only	Metcalfe, J.L et al, 1985
water 0.001 ug/l		nondetectable nondetectable		
water 0.003 ug/l		nondetectable nondetectable		
water 0.001 ug/l		nondetectable nondetectable		
water Nd		nondetectable 20 ng/g		
water 0.0014 mg/g 0.0023 mg/g 0.0040 mg/g 0.0034 mg/g		218 +/- mg/g 8.4 +/- 0.5 mg/g 154 +/- 8.0 mg/g 16.1 +/- 0.8 mg/g 13.2 +/- 0.7 mg/g 12.1 +/- 0.6 mg/g 13.6 +/- 0.7 mg/g 13.5 +/- 0.7 mg/g	example lake levels, study based on 5 lakes.	Metcalfe, J.L. et al, 1983
water Nd Nd Nd Nd Nd		1.7 +/- 0.2 < 0.7 6.4 +/- 0.7 .15 +/- 0.03 0.5 +/- 0.2 < 0.3 0.5 +/- 0.2 0.5 +/- 0.3		

Water ug/L	Hours		Duckweed ug/kg		
58.5+/-28.9		1.4	ns	water-4 replicates	Muir,D.C.G., et al,1982
37.1+/-21.1		10	2980+/-245	sediment-2 replicates	
17.6+/-3.8		24	2582+/-240	duckweed-3 replicates	
9.6+/-2.9		48	1245+/-125	cattails-3 replicates	
13.7+/-0.5		72	967+/-200	fish-2 replicates	
5.6+/-1.7		120	541+/-83		
5.0+/-1.6		240	286+/-49		

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
EHDPP	Cattails			
	Fish			
IPP	Duckweed			
	Cattails			
	Fish			

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
Water ug/L	Hours	Cattails ug/kg		
58.5+/-28.9	1.4	ns		
37.1+/-21.1	10	18+/-8		
17.6+/-3.8	24	8+/-9		
9.6+/-2.9	48	8+/-2		
13.7+/-0.5	72	23+/-12		
5.6+/-1.7	120	9+/-10		
5.0+/-1.6	240	13+/-7		
Water ug/L	Hours	Fish ug/kg		
58.5+/-28.9	1.4	ns		
37.1+/-21.1	10	8560+/-920		
17.6+/-3.8	24	5970+/-860		
9.6+/-2.9	48	7660+/-2600		
13.7+/-0.5	72	3990+/-680		
5.6+/-1.7	120	570+/-28		
5.0+/-1.6	240	8970+/-1050		
Water ug/L	Hours	Duckweed ug/kg		
63.5+/-6.3	1.4	ns		
36.8+/-2.8	10	2143+/-20		
26.0+/-15.3	24	2031+/-100		
16.8+/-0.1	48	1775+/-90		
14.4+/-0.3	72	1370+/-386		
12.2+/-0.8	120	766+/-33		
6.3+/-0.8	240	736+/-104		
Water ug/L	Hours	Cattails ug/kg		
63.5+/-6.3	1.4	ns		
36.8+/-2.8	10	4+/-1		
26.0+/-15.3	24	5+/-2		
16.8+/-0.1	48	12+/-5		
14.4+/-0.3	72	9+/-8		
12.2+/-0.8	120	42+/-36		
6.3+/-0.8	240	43+/-17		
Water ug/L	Hours	Fish ug/kg		
63.5+/-6.3	1.4	ns		
36.8+/-2.8	10	8070+/-2100		
26.0+/-15.3	24	10250+/-2140		
16.8+/-0.1	48	4004+/-14		
14.4+/-0.3	72	2750+/-0		
12.2+/-0.8	120	1740+/-550		
6.3+/-0.8	240	1530+/-1096		

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
Cd	algae			
	benthic insects			
Cu	algae			
	benthic insects			
Pb	algae			
	benthic insects			
Zn	algae			
	benthic insects			
HCB	Procambarus clarkii			
Cu	mayfly			
	stonefly			
Pb	mayfly			
Pb	stonefly			

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
<0.00007 ug/L		3.54 ug/g dry wt.		Anderson,R.V.
<0.00007 ug/L		2.27 ug/g dry wt.		et al,1978
0.001 ug/L		12.58 ug/g dry wt.		
0.001 ug/L		14.91 ug/g dry wt.		
<0.022		13.17 ug/g dry wt.		
<0.022		28.6 ug/g dry wt.		
<0.002		30.25 ug/g dry wt.		
<0.002		225.63 ug/g dry wt.		
0.005 ppb		Males -Females	2 specimens per	New Orleans
	1 day	33 101	data point	University 1976
	5 days	12 27		
	10 days	ND 15		
10 mg/L		9125 ug/g		Nehring,B.
4.82 mg/L		5787 ug/g		
2.51 mg/L		3882 ug/g		
1.22 mg/L		1933 ug/g		
0.63 mg/L		1240 ug/g		
0 mg/L		94.7 ug/g		
12.2 mg/L		2540 ug/g		
10.4 mg/L		2096 ug/g		
8.13 mg/L		1767 ug/g		
6.47 mg/L		1199 ug/g		
0 mg/L		122.3 ug/g		
9.24 mg/L		104700 ug/g		
4.9 mg/L		73200 ug/g		
2.34 mg/L		31780 ug/g		
1.32 mg/L		14560 ug/g		
0.69 mg/L		5702 ug/g		
0 mg/L		126.6 ug/g		
19.2 mg/L		8172 ug/g		
7.44 mg/L		2249 ug/g		
4.43 mg/L		1666 ug/g		
1.96 mg/L		736.6 ug/g		
1.09 mg/L		716.7 ug/g		
0 mg/L		8.18 ug/g		

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

CONTAMINANT	ORGANISM NAME	SIZE	% FAT	WEIGHT
Ag	mayfly			
	stonefly			
Zn	mayfly			
	stonefly			
Zinc	Amblema perplicata (clam)			
Cadmium	Amblema perplicata (clam)			

TABLE 5 - Examples of freshwater biomonitoring-exposures/accumulations with time-metals and organics

WATER/SUBSTRATE	TIME	CONCENTRATION	COMMENTS	REFERENCE
0.75 mg/L		65.31 ug/g		
0.4 mg/L		36.65 ug/g		
0.23 mg/L		47.97 ug/g		
0.12 mg/L		28.73 ug/g		
0.06 mg/L		25.32 ug/g		
0 mg/L		0 ug/g		
0.738 mg/L		53.28 ug/g		
0.399 mg/L		30.76 ug/g		
0.217 mg/L		22.95 ug/g		
0.105 mg/L		13.62 ug/g		
0.05 mg/L		9.13 ug/g		
0 mg/L		3.97 ug/g		
9.2 mg/L		2361 ug/g		
4.32 mg/L		2381 ug/g		
2.29 mg/L		2187 ug/g		
1.04 mg/L		2029 ug/g		
0.5 mg/L		1794 ug/g		
0 mg/L		1116 ug/g		
13.6 mg/L		561.2 ug/g		
5.54 mg/L		497.1 ug/g		
2.83 mg/L		415.7 ug/g		
1.61 mg/L		507.7 ug/g		
0.77 mg/L		439.4 ug/g		
0 mg/L		357.2 ug/g		
20.9 ug/L	7 days exposure	foot-170 ug/g dry wt. mantle-538 gill-956 digestive gland-208 viscera-232 whole body-388		Adams,T.G. et al,1981
3.16 ug/L		foot-1.54 mantle-9.08 gill-16.5 digestive gland-18.6 viscera-3.69 whole body-.78		

APPENDIX 1 - GLOSSARY OF TERMS

1) bioaccumulation - to accumulate within biological tissues by means of a biological (physiological) process

2) bioconcentration - the relative content of a component with respect to another component eg. the amount of diazinon in biological tissues of a fish with respect to the amount of diazinon in water

3) bioconcentration factor (BCF) - the concentration of contaminant in fish (for example) tissues divided by the concentration of the contaminant in the water body (eg. lake)

4) bioindicator - a living organism used to detect change within a living system

5) biological monitoring - includes the determination of the effects of pollution on all types of aquatic life

6) biomonitoring organism - any organism used to determine a change in body concentrations of contaminants with respect to previously formulated standards

7) effluent - liquid wastes from an industrial process, agricultural operation, municipal STP or dumpsite where treatment may or may not have taken place prior to release to the environment

8) hydrophilic - having an affinity for water

9) indicator species - eg. bivalves as a whole may be used to detect change

10) lipophilic _ having an affinity for fats of other lipids

11) monitoring - surveillance taken to ensure that previously formulated standards are being met

12) surveillance - a continued program of surveys systematically undertaken to provide a series of observations in time

13) survey - an exercise in which a set of standardized observations (or replicate samples) is taken from a station (or stations) within a short period of time to furnish qualitative descriptive data

14) transplanted - moved from one geographical area to another or from one part of an area (river, stream, lake) to another; usually contained ie. caged

15) young fish - fish hatched within a 12 month period of capture; size/weight relationships plus scale reading indicate age

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Nereis diversicolor	lab				60 days	sediments
Menidia menidia (Atlantic silversides) Mercenaria mercenaria (hard clams) Palaemonetes pugio (grass shrimp)	lab				10 day renewal	STP sludges
Mytilus edulis (mussel)	lab		5 cm.		4 days	
Leiostomus xanthurus (a demersal fish) Nereis virens (sandworm)	lab					contaminated sediment
Mytilus edulis	lab				24 hours	
Donax serra (bivalve) Bullia rhodostoma (intertidal gastropod)						

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
2 months		PCBs	accumulation and reached equilibrium in 40-60 days; depurated over 2 months to levels in unspiked sample; can uptake, depurate so available to biota. (remobilization)	Elder, D.L. et al 1979
2 days		Hg, Cd, PCBs, DDT and metabolites, petroleum hydrocarbons	used sludge in dilutions, organisms represent forager, filter feeder, detrital omnivore; could not tell if any uptake from sewage sludge	Maciorowski, A. F. et al 1985
		aminocarb, nonylphenol pesticide diluen. 585	max. concentration day 2,ND 1 day past exposure; concentration factor 1.0-1.9; 585 oil max. concentration day, 2 baseline I day past max concentration factor 330; nonylphenyl max. concentration day 2, decreased by day 4, not all gone 1day past, max. concentration factor 12-13,relatively low uptake, high excretion; > 0.1 mg/l not likely excretion; not likely to significantly contaminate bivalves	McLeese, D.W. et al 1980
		PCBs	both accumulated PCBs from water and sediments	Rubinstein, N.I. et al 1984
		pesticides	molluscs have been found deficient in the mixed function oxidase system that metabolizes xenobiotics, therefore, elimination there is slow compared to fish, crustaceans; 7 pesticides - inverse relationship between water solubility bioaccumulation factor.	Nolan, C.V. et al 1983
			South Africa - national marine pollution monitoring program evaluating these.	Watling, H.R. et al 1983

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

ORGANISM	FIELD/LAB NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Nitocia spinipes (crustacea)	lab				magnesium production
Spartina alterniflora (saltmarsh cordgrass)	lab				
Fundulus similis (killifish)	lab			11 days	
Pseudorasbora parva (topmouth gudgeon) Carassius auratus (silvercrucian carp) Cyprinus carpio (carp) Lebistes reticulatus (guppy) Procambarus clarkii (crayfish) Indoplanorbis exustus (redsnail) Cipangopoludina malleata (pond snail)	lab			7,14 days	
Gielichthysmciabilis (mudsucker or sand goby) Citharichthys stigmaeas (sand dab) Oligocuttus maculosus (sculpin)	lab				

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		6 chlorostyrenes penta-,transhexa-, transhepta-, cishepta-, BB-hepta-,octa-		Tarnpra, M. et al 1985
		PCBs	potential pathway of PCBs from estuarine sediments; selective uptake of lesser chlorinated componerts.	Mrozek, E. Jr. et al 1981
		hexachlorobenzene	t1/2 9.3 hours, to control levels in 48 hours, bioaccumulation to lesser extent in marine environment average BF 375.	Glam, C.S. et al 1980
			bioconcentration higher for fish gudgeon top 152;at 10 ppb gudgeon reached equilibrium at 3 days; elimination linearly rapid;BCR had increased proportional to body wt.	Kanazawa, J.,1978
	tissues	PAH's (H-3,4-benzo pyrene, naphthalene) major metabolites -H-7,8 - dihydro - 7,8-dehydroxy benzopyrene;1,2 - dihydro - 1,2 - dihydroxy naphthalene	entrance through gills, metabolism by liver, transfer of HC's and metabolites to bile, excretion; gall bladder major storage; uptake in minutes; urine important excretion; fish can flush out naphthalene and metabolite at a greater rate than benzopyrene and metabolite -detoxification mechanism.	Lee, R.F. et al 1972

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Cernstoderma edule Mya arenaria Arenicola marina Crangon crangon Solea solea		samples from each		wet and dry wts.		
Salmo salar (Baltic salmon) Salmo trutta (Bothnian Bay trout)	field					
Dunaliella sp. (algal flagellate) Brachionus plicatilis (rotifer) Engraulis mordax (anchovy)	lab (marine simulation)			dry wt.	45 days	
Dunaliella tertiolecta Chlorococcum sp. Nitzchia sp. Thalassiosira pseudonana (alga)	lab					
Spartina alterniflora (cordgrass)	lab					
Mytilus edulis	field (caging)	30 x 12	40 60 mm.	wet wt.	Jan May 10 day intervals collected	

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		organochlorines PCBs, DDT	marine animals accumulate PCBs and DDT differently; inconsistency of the pattern of residues in animals from same area indicates field bioaccumulation is species and compound specific; PCBs concentration on wet wt. positive correlation, PCB levels on lipid basis increase from bivalves to fish correlated to trophic levels.	Goerke, H. et al 1979
	muscles,livers unfertilized eggs	PCBs, DDT, HCB lindane, 2,3,6-trichloro cymene, 10 chlorophenols	found these in muscle, livers, unfertilized eggs; chlorohydro carbons significant positive correlation with wt., fat content; 10 of 17 chlorophenols detected but only in livers; for chlorophenols look at fresh wt. not lipids.	Vuorinen, P.J. et al 1985
		chlorinated hydrocarbons	PCBs on dry wt. basis amplified up food chain but on lipid basis it was not apparent at lower levels fish 10 x higher than invertebrates but fed and unfed anchovy had same levels so through water final PCB concentration related to that in water - diffusive interaction.	Scerra, E.D. et al 1979
		chloronaphthalene	bioaccumulation was related to chlorine content but it was not great, 140 was highest CF.	Walsh, G.E. et al 1977
		PCBs	cordgrass presents a potential way for the mobilization of PCBs from estuarine sediments.	Mrozek, E. Jr. . et al 1981
	somatic and gondal tissues	benzo (a) pyrene (BAP)	BAP occurred primarily in somatic tissues, whole body BAP was in somatic tissues so seasonality had no impact.	Mix, M.C. et al 1982

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ORGANISM	FIELD/LAB NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Polychaetes juvenile sea mullet	field, lab				
Rhepoxynius arbonius Eohaustorius washingtonianus (amphipods) Macoma nasuta (clams) Pandalus platyceros (shrimp) Parophrys vetulus (fish)	lab			4 weeks	urban estuary
Mytilus edulis (mussel) eel short-necked clam	lab				refineries petrochemicals
Mya arenaria L. (soft shell clam)	lab	25 mm.		28 days	oil spill in winter

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		PCBs	water important uptake route although at high levels birds take it up through food; in lab equilibrium between sediments and organic takes 10 -12 weeks; high uptake occurs at low concentration's with small increases causing substantial increases in sediment concentration; with petroleum hydrocarbons in sediments. PCB uptake by polychaetes is reduced.	Shaw, G.R. et al 1982
4-24 hours	hepato-pancreas,liver bile	aromatic hydrocarbons H benzo (a) pyrene, phenanthene, anthracene, fluoranthene, chrysene, benzopyrenes, indenopyrene	mixed AHs and HBAP; metabolism of HBAP (indicative of mixed function oxidase) was negative correlation tissue concentration's M. nasuta < E.washinton < R. abronius < P. platyceros equilibrium P. vetulus of AH's ; amphipods accumulated higher concentration's of AH's than clams (so other factors at work);4 wks. with sediments BAP no change but HBAP was taken up - clam hepatopancreas 5 x > fish live and 10 x > shrimp hepatopancreas; clams had 3-6 ring AH's; amphipods 4 and 5 ring; fish took up BAP in bile; shrimp, fish less AH's than clams.	Varanasi, U. et al 1985
		dibenzothiophene (DBT)	t1/2 9 days; accumulation in mussel 600-800 x levels in water after 4-8 days; mussels higher accumulation eels, clams; results show mussel level does not reflect accidental pollution by continuous input of organosulfur compounds.	Kria, S. et al 1983
14 days t1/2 11-50 days		naphthalene, methyl substituted naphthalene isomers.	clams ejected lots of mucous; at high concentrations 50-100 ppm.filtration rate reduced; took up with respect to water concentration; in 1st wk.depuration rapid then slows so not all naphthalene gone.	Stainken, D. ,1976

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Rangia cuneata (clams)	lab				24 hours	
Corbicula japonica (shell fish)	transferred clean fish to contaminated site			mean wt. 10.1+/- 1.5 g.	biweekly May to Aug. monthly Sept. to Dec.	herbicide treatment of rice paddies
Clupea harengus (B.herring) Stizostedion eucioperca (pike perch) Lota lota (burbot)		1 comp.				
Homarus americanus (American lobster)	field/lab			shell fish ng/g wet wt. oysters 9.4 mussels 45 lobster 2300 digestive gland, 281 tail		coal-coking plant
Panulirus argus (spiny lobster)	lab					

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
480 hours		radioactive benzo (a)pyrene (BAP-C)	0.0305 ppm. - 24 hours. - 480 hours x/- 7.2 ppm.; 75% in viscera (digestive gland, gonads, heart); mantle, gills, adductor muscle fat each had 3.5 - 10%; clean water 70% release in 10 days 20 days 0.1 ppm. left; 2nd expt. -5.7 ppm. in 24 hours complete depuration 30-58 days.	Neff, J.M. et al 1975
		1,3,5-trichloro-2-(4-nitrophen-oxy)benzene (CNP)	reached max. 0.42 ppb. May 29, ND after; water max. 1 wk. after applications; BCF 4000; during decreasing period a linear relationship between log of concentration and elapsed time; t1/2 10.4 days; log linear relation not applicable after 20 weeks so some of CNP came from sediments.	Okyama T., et al 1986
		polycyclic aromatic hydro-carbons (PAH's)	PAH's < 0.5 - 148 ug/kg in mussels; only a few of 14 PAH's found in fish muscle; tend to accumulate in liver and gall bladder of fish.	Rainio, R. et al 1986
12 months	hepatopancreas mid-gut gland; tail muscle	polycyclic aromatic hydrocarbons	did not lose substantial amounts after 12 months; those which did decrease were those of greater water solubility; metabolize very slowly; boiling or steaming lobsters result in elevated levels in tail meat (from digestive gland.)	Uthe, J.F. et al 1986
	hepato pancreas green gland gonads heart muscle gills	phenanthrene (C labelled) octachlorostyrene	crustaceans metabolize phenanthrene which results in more rapid elimination from hepato pancreas, 2 weeks after dosing 1/2 of radioactivity still in tissues; octachlorostyrene higher in hepato pancreas; muscle and green glands= gills and heart phenanthrene highest	Solbakken, J.E. et al 1986

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

ORGANISM	FIELD/LAB	NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Abra nitida (deposit-feeding bivalve)	lab (flow-through system)	10 adult	10 +/- 2 mm.			
shell fish fish	field	20-25 shellfish 4-8 fish (7 marine fish)				
fish	field			wet wt.		
Mytilus edulis (mussel) Littorina littorea (periwinkle)	lab (natural conditions)				4-16 months exposed to 29 and 123 ppb diesel oil; mussels also 8 days to 29 ppb.	
Salmo salar (Atlantic salmon)	lab					fish food

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		hexachlorobenzene lindane	contributions from food, suspended particles, water; hydrophobic attached to suspended particles sediments and unavailable unless taken in; accumulation ratio higher when suspended particles added; lindane less hydrophobic so values lower, but bio-accumulation in presence of suspended solids = same; accumulation of HCB higher in the presence of added particles; uptake via food predominates.	Ekelund, R. et al 1987
		organochlorine pesticides	looked at shellfish and fish on a wet wt. basis rather then lipid wt; levels found reflect feeding and migratory behaviour.	Ober A. et al 1987
		polynuclear aromatic hydrocarbons (PAH's)	PAH's- high molecular wts. nonpolar nature, low water solubility but can still accumulate in fish; sediments had 16 PAH's; naphthalene found 14-106 mg/kg; acenaphthalene 1-69 mg/kg; fish can metabolize PAH's and excrete them as water soluble metabolites.	DouAbdul, A.A.Z. et al 1987
		polynuclear aromatic hydrocarbons	mussels 8 days rapid uptake; lysosomal stability significantly reduced after 1 day to 29 ppb; PAH in long term exposed tissues of both animals (tissue concentration highest in 125 ppb); cytochrome P-450 monoxygenase or mixed function oxidase system involved in detoxification of foreign organic matter in tissues.	
		de,-tetra-bromo, and chlorobiphenyls, hexabromobenzene	no major differences between accumulation of di-and tetra-bromo-and chlorobiphenyls by fish; hexabromo benzene not accumulated from water of food chloro -and bromo-substitute compounds accumulate higher from water.	Zitko, V. et al 1976

APPENDIX 2 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - ORGANICS.

ORGANISM	FIELD/LAB NUMBER	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
bivalves (marine) C. virginica M. arcenaria M.mercenaria	field				sediments, old spills

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DEPUR. PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		PCBs	sediments 3.4 - 2035 ng/g C.virginica 81 +/- 32 M. arenaria 149 +/- 67 M. mercenaria 131+/- 27 may be selective uptake ie. lower chlorinated isomers tend to accumulate in tissue more frequently.	Stainken, D. et al 1979.

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABCRATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Protothaca staminea (clam)	lab				48 hours	
Nereis virens Macoma balthica Crangon septempimosa	lab		narrow size range			sediments
Nereis virens (deposit feeding polychaete)	lab				24 days	
Crassotrea virginica (osyte.) Mytilus edulis (mussel)	lab				12 weeks	simulating environment levels
C. virginica, Rangia cuneata(clam)	lab					
Crassostre. virginica (Eastern oyster)	lab					

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	gills	Cd	no sediments, clam gills accumulate Cd rapidly from seawater; gills major route for bioaccumulation of dissolved trace metals; sediments added, Cd adsorbs to sediment particles.	Hardy, J.T. et al 1981
		Cu, Zn, Cd, Pb	other factors control availability of metals to organisms not just levels in sediments; only M. bathica practical for short-term use; N. virens good for Cd, Pb bioavailability; demonstrated effect of EDTA; when organism tissue metal level changed - uptake rapid, slow decline to steady state; interspecies differences could be related to feeding habits.	Ray, S. et al 1981
		Cd	small > uptake than large; in 24 days 28-54% > than large; water concentration determines concentration in sediments and in worms; uptake from water virtually no excretion.	Ray, S. et al 1980
	soft tissues	Ni	significant linear relationship soft tissue concentration and water level; water 5 and 10 mg/kg oyster accumulated 9.62 +/- 5.15 mg dry wt.l mussel 10.4 +/- 2.66 and 16.43 +/- 3.13 mg; Ni loss not time or temperature dependent; t 1/2 for M. edulis 1/2 [illegible] virginica; M.edulis better, Ni concentration higher less variability.	Zarrogian, G.E. et al 1984
		Se, Fe, As, Cu, Zn	no metal/wt. relationship- correlation Se and Fe with wt. (decline in metal with age); significant positive correlation Cu, Zn, in other studies.	Lytle, F.F. et al 1982
	gills	Hg	took up all forms rapidly; accumulated in gills.	Kopfler, F.C., 1974

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Mercenaria mercenaria	field					
Water hyacinth	lab					
D. serra B. rhodostoma	lab	20/ treatment			3 weeks	
Mytilus edulis	field	11 months x 13 months	20 size classes, 15-20 species, small 12-16mm. 2 or 3 intermed.	wet wts. dry wts.		
Mytilus edulis	lab				9 months	

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		Cd, Cu, Fe, Pb, Zn	all tissue metal concentration varied significantly with season; Cd, Pb concentration in sediments &tissues of similar magnitude (not regulated); Cu, Zn higher in sediments (actively taken up and metabolized)	Genest, P.E. et al 1981
		Zn	pH 5 increase in inital rapid uptake; 5-10 uptake constant; < 5 uptake hindered; Zn uptake 2 phased 1st 4 hours rapid; 2nd slower, near linear; stirring enhanced Cd uptake; Zn initial rapid uptake limited by diffusion; as solution volume increases amount of Zn remov. d increases at near linear rate; 6 metals hinde. Zn uptake - Fe, Cu, Hg, Ni, Co, Cd.	Hardy, J.K. et al 1985
		Cd	tissue Cd concentration increase with increase in water concentration; gill >>> digestive gland > muscle > mantle > gonad > foot >/= syphon.	Watling, H.R. et al 1983
24 hours		metals, Cu, Pb, Mn	same shell - more water therefore dry wts. need; Cu large clams less than small (regulate it but still can accumulate large amounts); higher Pb in summer except Pb, Mn metal higher in winter; trace concentration decrease with increasing size.	Popham, J.D. et al 1983
	somatic, gonadal tissues	Ni, Mn, Zn, Cu, Cd, V	except Cu all others highest in winter/early spring; (gonadal); no Cu seasonal change; somatic Ni, Mn, Zn max. early spring; somatic - Cu, Cd, V fluctuated irregularly (not related to spawning or gametogenesis.); metals more abundent in somatic; believe gonadal wts. & somatic analyzed separately should sample same time each year from same population.	LaTouche, Y.D. et al 1981

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Gambusia affinis (mosquito fish)	lab					
Austromytilus erosus (shellfish) Mytilus edulis Katelysia Scalarina Pinna bicolor (bivalves) Penaeds latisulcatus (King prawns) Cynidoglanis macrocephalus (cobbler), Pseudorhombus junynsii (flounder), Hyporhamphus melanochir (garfish), Atherinosoma elongata (hardy heads) Arripis georgianus (herring) Aseraggodes haackeanus haackeanus (sole)	field		4-5 cm. 5.5-6.5 3.5-4.0 cm.			fish, vegetable processing abattoir, super P plant, woollen mills, town runoff, railway yards, lead-acid accumulating merchant.
Salvelinus namaycush	field					
flatfish (juvenile) shrimps	field					

APPENDIX 3 MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		2 Hg compounds	methylated more toxic, accumulation easier - easier penetration of membrane barriers (liposolubility); higher capacity for intracellular storage so increases biological t1/2	Boudou, A. et al 1979
		heavy metals, Pb	high Pb in cockles, mussels, not in sediments M. edulis does not reflect metals in sediments because it is from the water column; important to consider the form of metal in the discharge.	Talbot, V. 1983
		Hg	Hg levels correlate to fish length; difference among lakes related to Hg in water.	MacCrimmon, H.R. et al 1983
	whole animal	Zn	fish Zn concentration body wt. source of variablity; 0 group Zn concentration inversely related to body wt. over 1st 2 years concentration decreased with growth but seasonal fluctuations, so increase in 1st. winter.	Milner, N.J. 1979

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Argopecten irradiens (bay scallop) Argopecten gibbus	lab					
Macoma balthica (bivalve)	field	20-30 monthly	pooled according to shell length	soft tissue dry wt		
Crassostrea virginica	lab/ field					
Balanus ebruneus	field			dry weight		
Mytilus edulis	field/ lab		25 6-8 cm.			

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		Ca, Cr, Cu, Cd, Mn	emphasis on kidney for anindicator of metals; concretions in kidney; species diff. in Ca, Mn, Cd, Cu, Cr; needs more work.	Carmichael, N.F. et al 1979
2 days	whole body	Cu, Ag	body size and concentration of Cu, Ag varied, short term study metal uptake by small more rapid than uptake by large ones; growth may dilute concentration's growth more rapid in young; +ve correlation size/metal concentration - net uptake of some metals may occur throughout the life ; equilibration of somemay occur; in periods of slow growth metals increased more rapidly in small (vice-versa); short/long term - young/old; to compare chronic contamination among stations age is crucial; to access temporal fluctuation several age classes; suggests collecting a range rather than 1 size	Strong, C.R. et al, 1981
6 months only lost 25% first 2, next 42 days rapid loss of Cd		Zn (2000 ppm) Cd	uptake seasonally dependent, rapid summer/fa": Cd unbound; days 43-60, 74-104 lack of elimination; could be due to bound; others show slow release	Mowdy, D.E. 1981
		Cu, Zn	Florida, use barnacle; results show a 1 ppb increase in dissolved Cu brings a 36 ppm. increase in Cu levels.	Barber, S. et al 1981
	tissues combined	radionuclides Zn, Mn, Co, Fe	greatest accumulation stomach, digestive gland; when animals starved most noticed in digestive gland and foot (Fe loss bysuss gland of foot); nuclides accumulated via particulate matter mucous capeble of sequestering it; feel water plays a minor role in nuclide uptake.	Pentreath, R.J. 1973

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Saccostrea cucculiata Saccostrea sp. (oysters)	field	15 (3 pooled samples of 5)	40-60 mm. 25 35 mm.	often as wet wt. but shells often cracked so not true wet wt.		
Mytilus edulis	lab					
Mytilus edulis	lab/ field caging				100 days	
Corbicula fluminea (Asiatic clam)	lab (artif. stream)	4 clams/ sampling time	10-30 mm.	dry wt.	4 weeks	
Mytilus edulis (bay mussel)	field	20				
Ostrea edulis (oyster)						

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DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		Ag, Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn	problems with shape of oysters in getting correct size.	Talbot, V. 1985
		Cd	significant equilibrium relationship between total recoverable Cd in seawater and concentration in mussel; concentration in water should not exceed 0.2 ug/l if the mussel is not to reach a Cd concentration of mg/kg wet wt. concentration factor is then 9950; have to watch wt/length - seasons	Talbot, V. 1985
	individual whole mussels	Hg	caged clams reached Hg concentration's of native ones after 100 days; in lab after 20 days Hg concentration 20 ngl/l a significant change in Hg concentration; water samples did not reflect Hg in mussels.	Davis, I.M. et al 1978
36 hours		Cd, Cu, Zn	Cd 0.023 mg/l - 3770 Cu 0.016 mg/l - 22,571 Zn 0.433 mg/l -358 Cd,Cu same pattern of accumulation at all concentration's Cu, Zn concentration and length of exposure influenced uptake; no steady state for Zn, none after 28 days for Cu, Cd steady at 0.055 mg/l.	Granev, R.L. Jr. et al 1983
	somatic and gonadal tissues separately	Cu, Ni, Mn, Zn, Cd, V	gonadal and somatic tissues should be analyzed separately; Zn taken up by somatic tissue then gonadal; tissue weights should be recorded tissues analyzed separately.	LaTouche, Y.D. et al 1981
		Cu, Zn	both localized in the haemolymph amoebocytes which penetrate all soft tissues.	George, S.G. et al 1978

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ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Spartina alterniflora Spartina patens (marsh grasses) U. pugnax (fiddler crab) mussels	exptl marsh					sewage sludge
oysters	field			dry wt.		
Mytilus edulis (common blue mussel)	field	20		dry wt.		point source, storm drain
Mytilus galloprovincialis (mussels)	lab (simul. marine)					
Nereis nereis Mercenaria mercenaria Palaemonetes pugio	lab				100 days	dredged sediments
Mytilus edulis (mussel)	field	50	3-7 cm.	dry matter	collected April-Oct. 1979-83.	

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	roots leaves	Hg	sediment Hg increased 3-6 fold, no increase in crabs, mussels, grasses; as sediment organic matter decreased - uptake in the biota, if heavy Hg input roots of Spartina take it up but it is not translocated.	Breteler, R.J. et al 1981
	shell, soft tissues	Fe,Mn,Cu,Zn,Ag	correlation between metals in soft tissues suggest that Fe and Mn; Cu, Zn and Ag form 2 groups concentrated similarily; Mn more concentrated in shell; the geochemical characteristics are an important control in uptake.	Windom, H.L. et al 1972
overnight	soft parts	Cu, Zn, Pb	precise location of source 0.5 km. and 30 m. differences noted.	Popham, J.D., et al 1980
92 days for mussel to loose 128,000 ppb. of Hg.		Cd, Pb, Cu, Hg	Hg at 10 ppb. - 40,000 ppb rapid accum. 100 ppb. - 100.000 ppb. 200 ppb. - 130,000 ppb. at 500 ppb accumulation velocily and final concentration in mussel diminishes (poor health)	Majori, L. et al 1973
		PCBs, Hg, Cd	only PCBs above back ground; sandworm can takeup, depurate, sediments to water; others in water; steady state reached for N. virens; organic content of soil has bearing; no metals accumulated likely bound to sedime: :.	Rubinstein, N.I. et al 198.
		Hg, Pb, Cd, Cu, Zn	Netherlands - Joint Monitoring Programme inlcudes coord. monitoring of Convention of Oslo 1972 and Paris 1974; Pb in spawning mussels higher than pre-spawn so is Cd.	Luten, J.B. et al 1986

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Mytilus edulis (mussel)	field		shell lengths	wet wts. wet/dry wt.ratios	Oct. and March (late winter and late summer in Aust.)	
mussels	field/ transplant technique considered as useful.			dry wt.		
Crassostrea gigas (Pacific oyster)	field	20/age group				
Choromytilus meridionalis (mussel)	field				collected June/Nov.	
Mytilus edulis (mussel)	field caging		20 50-60 mm.	dry wt		
- - - - - - - -	lab					

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
48 hours	individuals separate body tissues	Zn, Cd, Cu	do not use mussels as Cu indicator in marine environment metal variations related to wet wt.; seasonal wt. minima in late winter but no difference in metal concentration's; the wt. variations produce any observed seasonality.	Philips, D.J.H. et al 1976
		Cu, Zn, Cd, Pb, Hg	Cd concentration independant of dry wt.; Scottish mussel watch.	Davis, I.M. et al 1980
		Cd, Zn, Cr, Cu, Pb	1 ppm. in mud - 25 ppm. Cd in oyster (4-5 ppm. wet wt.); oyster size controls physiological process so Cu, Cr only to a max. concentration; Cd, Zn concentration depended on amount available; Pb met levels at site;collected Feb/Mar	Ayling G.M.1974
72 hours		Cu, Fe, Pb, Zn, Mn	South Africa mussel watch; from June to Nov. mean water increased sign. 79-81.5% for Hg; males increased for Cu, Fe, Pb, Zn, Mn females increased Fe, Pb, Cd, Cu Zn; suggest using only sexually immature individuals.	Oiren, M.J. et al 1980
	soft tissues	metals	transferred to clean water Cu decreased but not Cd (also lost wt) 79% of residual Hg was lost in 80 days; gonads partially spawned in May/June.	Simpson, R.D. 1979
			animals exposed to metals can synthesize low molecular wt. proteins called metallothioneins which are rich in sulfhydryl group which bind metal cations.	Lobel, P.B. et al d1984

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Crassostrea virginica (oyster)		10		dry and wet wt.		
Argopecten irradiens (bay scallops)	lab				96 hours	
Crassostrea virginica (oyster)	lab				11 weeks to mud; 11 wks. to sand	
green mussel	lab				5 weeks	
Crassostrea virginica (eastern oyster)	lab				11 days	
Mytilus edulis (mussel)	lab	mean separate analysis for 3			6 weeks	

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	soft tissues	Zn, Fe, Cu, Mn, Cd	rapid growth in spring; spawning (wt. loss); 2nd period rapid growth depletion of glycogen stores in winter; soft tissues Zn>>Fe>Cu>Mn >Cd; shell Mn>>Fe>Zn>Cu>Cd;Mn, Fe involved in shell growth high turnover rate of Mn in soft tissue during shell growth; Zn, Cu Cd synamics related to gonadal development and spawning; rapid discharge of metals in summer due to biochemical and physiological readjustments related to gametogenesis.	Frazier, J.M. 1975
		As, Cd, Hg, Ag	all accumulated in significant amounts.	Nelson, D.A. et al, 1976
		Ag, Cu	exposed to muddy sediments no significant Ag, Cu uptake; exposed to sand no Cu uptake, oysters retain their metal content when transferred to clean water.	Greig, R.A. et al 1978
	soft tissues	Cu, Zn	bioaccumulation linear; in controls Cu was constant, Zn increased, metal uptake proportional to water concentration	D'Silva, C. et al 1978
		Hg (inorganic)	low concentration mercuric chloride - significant levels Hg; accumulated in 2 distant phases in linear way over 11 days no food so uptake thorugh gill/ mantle; rapid uptake - reversible, then shifts to linear form - irreversible.	Mason, J.W. et al 1976
	gill, kidney, adductor muscle, foot, mantle	Pb	various Pb concentration's uptake similar, linear 1st 40 days 35 days small took up Pb 2.5 x faster; 5 weeks in seawater decrease in Pb,kidney highest, foot and mantle low; kidney loss highest rate.	Schulz-Baldes, M. 1974

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Mercenaria mercenaria (quahog clams)	lab	20	40-75 mm.			
Perna perna (brown mussel)	lab		60-80 mm.			
Mytilus galloprovincialis (mussel)	lab	10/tank				
Crassostrea virginica	lab		10.2 +/- 1.2 cm.			

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	mantle tissue	Hg	at low dose Hg seems to cause loss of Fe from mantle fringes; ingestion suspended particulate indigestion by preconcentration complexing of metals by coordinate linkage with appropriate organic molecules; incorporation of ions into important metabolic systems; uptake onto mucus sheets.	Fowler, B.A. et al 1975
		Hg, Cd, Cu, Zn, Se, Ag, Ni, Cr, Pb, As	South African National Marine Pollution Monitoring Programme; Hg, Cd reduce filtering rate; Mn increases it; Se & Hg - antagonistic; As, Ni did not alter rate.	Watlin, H.R. et al 1982
24 hours - 2 weeks		radiotracer As	accumulation with tempature uptake rate decreased after 17 days - equilibrium As not related to water concentration; soft parts collect more but some on shell; smaller individuals had more temp. 13-20 C when no relationship with As so may be another form; byssus formation is a way of lowering As as in organic increases at low salinities although body parts, shell have similar at all salinities; if 2 wks. and depuration period, would not lose any more.	Unlu, M.Y. et al 1979
	individual tissues	Cd	no value in using specific tissues over whole soft parts; wt. decreases in spawning - increase in Cd; * higher Cd in smaller animals; distribution visceral > gill > = mantle; at low temperature 0 C significant difference in Cd concentration; gills high level binding to mucus sheets; Cd concentration versus Cd content.	Zaroogian, G.E. 1980

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Mytilus edulis	lab/field caging	25 juvenile	mean 26.5 mm.		25 days	
Ostrea edulis (oyster)	lab		8 diameter 7 & 8 cm.		48 hours	
Neanthes virens	lab			dry wt.	24 hours	
Mytilus edulis	field transplant (nylon baskets)	3 kg. 75	30-70 mm.	dry matter	clean to dirty 70 days; dirty to clean 77 days	
fish (12 species) shell fish (12 species)	field			dry wt. although % water induced to convert.		industrial, non-industrial areas.
Valencia hispanica (fish)	field		females sign. larger than males			Hg marsh

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
	shell	Cd	100 ug/l Cd did not affect filtering 500 ug/l did; showing greater growth in field than lab; for Cd in shell process is a reaction with shell matrix, only small amts. incorporated directly to carbonate crystal lattice; metal incorporation gives a different story from soft tissues.	Sturesson, U. 1978
		Hg	Hg in gills in 48 hours more rapid than digestive gland; binds to protein which is lost if starved; no simple relationship between soluable protein in gills, digestive and Hg concentration but the large surface area of gills, permeability passing on Hg to tissues, binding site due to high protein content may account for high equilibrium concentration factor.	Wrench, J.J. 1978
		Ag	exposed to 0.3 - 8.8 +/- 8.6 ppm. 0.8 - 74.6 +/- 46 ppm. 1.0 - 209 +/- 48.5 ppm. at 0.5 cont. to increase for 72 hours; did not accumulate according to size but water concentration	Pereira, J.J. et al 1981
77 days		Cd, Zn	not eliminated in area thought unpolluted; under natural conditions accumulation is linear as a function of exposure time.	Luten, J.B. et al 1986
		As	differences in As noted between areas of pollution; not in water samples but in others; fishes lower then shellfish or crustaceans.	Maria, I. Santa et al 1986
		Hg	no wt/Hg length/Hg relationships; since Hg levels low in area there may actually be a relationship; fish is omnivorous, sometimes predaceous.	Rincon, F.G. et al 1986

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Procambarus clarkii (red crayfish) Liza ramada (grey mullet) Mugil cephalus Mugil capito Pacificus lenius_ulus	field					
7 molluse species 3 crustacea 2 shell fish		composites 24-30 of small, 4 8 of bigger		dry wt. but show water cont nt for conversion.		
Crassostrea virginica Rangia cuneata	field			wet wt. converted to dry wt.		sediments
Argopecten irradiens Argopecten gibbus (bivalves)	lab					
Mytilus edulis (mussel)	lab					
Crassostrea virginica (eastern oyster)	field	5/site				
mussels	lab	80/tank	2.5-6cm.	dry wt.		

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		Hg	no differences between Hg concentration in sexes; different in both species attributed to feeding, mullet's cathadromic habit reflected in Hg levels; crayfish size/Hg concentration relationship even though not a contaminated area; in mullet (migrated) there was no significant difference in Hg/size although it was contaminated, refutes theory.	Rincon, F. et al 1987
		Cd, Pb, Cu, Ni, Zn, Fe,Sb	Cd, Pb, Cu, Ni highest in molluscs; Zn and Fe highest in crustaceans; Cu and Sb accumulated similarly by molluscs and crustaceans	Ober A.G. et al 1987
		Be, Cd, Cr, Cu, Pb, Ag, Zn, Tl	thallium not detected in tissue samples.	Byrne, C.J. et al 1986
	kidney		used x-ray micro analysis; when expressed relative to calcium content A. irradiens had higher amounts of Mg, lesser amts. of Mn, Zn; A. gibbus had a smaller proportion of Ca by wt. but higher levels of Cd, Cu, Cr, kidney concretions might be a sensitive monitor.	Carmichael, N.G. et al 1979
		Cu	mean total Cu 0.021 ppm. - sharp adduction of shell valves; as Cu rises a testing behaviour occurs shell closes; complete shell closure operates at added Cu concentration of 0.2 ppm.	Davenport J. et al 1978
	individual analysis on whole animal (without shell)	Cu, Zn, Cd	100-300% difference in concentration is determined from wt.; age vs. metal concentration - no relationship; linear relationship between Cu and Zn and Cd in uncontaminated clams; metals in low salinity could be dangerous.	Huggett, R.J. et al 1973
		Cu	fed algae; concentration in control Cu 0.00 ng/l; 2 distinct parts Cu m>/- 0.3 ng/ml Cu </= 0.01 ug/ml.	Martin, J.L.M. 1979

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Crassostrea virginica	lab				40 days	
Mytilus edulis	field		0.8-6.5 cm. < 2.3 cm.	0.07 g. dry wt.		
Mytilus californianus	field caging	3 mussels	immature 3.5 - 8.5 cm.		24 weeks 2-4 weeks intervals	
Mytilus edulis	field			wet wt.		
Crassostrea virginica	lab				20 weeks	
Mytilus galloprovincialis (mussels) Lysmata seticaudata (shrimp)	lab					
Mytilus edulis	field	50 200 122	55+/-3 mm 7-80 mm 11-78 mm	dry wt. with conversion to wet wt.		

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		Cd chelating agent (EDTA, NTA humic acid)	uptake greatest in gill mantle hepato pancreas, least in adductor muscle; exposed to 0.5 mg.ml Cd; chelators decrease accumulation except in adductor muscle; rate greater at high water temperature.	Hung, Yen-Wan, 1982
		Cd	immature show constant regression coefficient relating > Cd concentration to body wt.	Cossa, D. et al 1979
	composite samples	Hg	no relationship to depth digestive gland uptake 2-5 weeks, after 12 wks. adductor did not increase substitute; gonadal tissue gradual increase first 12 weeks, highest 16-20 weeks.	Eganhouse, R.P. et al 1978
		As	As positive correlated with somatic tissue wt.; As somatic and gonadal tissues similar; other metals somatic tissues always higher; seems unnecessary to separate tissues for As.	Latouche, Y.D. et al 1982
was curvilinar		Pb	siginificant linear relationship Pb uptake and water Pb concentration; Pb uptake curvilinear; water 1.0 mg Pb kg - tissue concentration increased; believe excellent for Pb.	Zaroogian, G.E. et al 1978
		Se, Se-75 radionuclide	shrimp high concentration - exoskeleton molts had 60-90% total Se-75 body burden when uptake in food highest in viscerel mass;high levels Se-75 in exoskelton shows translocated internal to external; in musse highest in visceral; only small fraction shrimp's Se content lost with molt; Se mantle lowest	Fowler, S.W. et al
		Pb	Pb should not exceed 1.27 ug/l in seawater or lead wet wt. of 2.5 mg/kg will be reached,do not necessarily correlate Pb with age	Talbot,V. 1987

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

ORGANISM	FIELD/ LAB	NUMBER OF ORGANISMS	SIZE (LENGTH)	WET/DRY WEIGHT	EXPOSURE PERIOD	POLLUTION SOURCE
Sacrostrea cucullata	field			wet,dry wts.		from sewage, antifouling paint, iron ore,coolant from electricity power generating station

APPENDIX 3 - MARINE LITERATURE ON FIELD AND LABORATORY STUDIES USING BIOMONITORING ORGANISMS - METALS.

DEPURATION PERIOD	COMPONENT ANALYZED	CONTAMINANTS	COMMENTS	REFERENCE
		Cu,Zn	metal content appeared to decrease with decreasing body weight after spawning; must take into account water dynamics, turbidity,suspended solids load versus metal concentration	Talbot,V.1986

APPENDIX 4 - KEYWORDS USED IN THE ELECTRONIC DATABASE

bacteria
bivalve(s)
bioaccumulation
bluegills
biological monitor
behaviour
benthic bioassay(s)
biological indicator
biomonitoring
benthos
biological sampling
biomagnification
bioconcentration
bromobiphenyls
bacteria
body burdens
benthic macrophytes
body weight
barnacle
bleached kraft mill
bioavailability
biological integrity
benzo(a)pyrene,BAP
cadmium,Cd
copper, Cu
Chlorella
clam(s)
chlorinated organics
chironomids
caddisfly
crayfish
caging, caged
chlorine
contaminated sediment
cellulose industry
chlorinated hydrocarbons
chlorinated phenolics
community structure
contaminant(s)
Cladophora
chemical residue(s)
chlorobiphenyls
chlorinated aromatic hydrocarbons
chlorinated phenols
culture, culturing
chromium, Cr
calcification
cytosomes
crab(s)
compartmentation
chemical pollutants
cobalt, Co
chelators
chlorophenol
[illegible]
crustacea
CNP
[illegible] ing plant
copper nickel smelters
chlorinated benzenes
carp
Chaoborus
chlorophenols
catfish
DDT
Daphnia magna
diet
diazinon
depuration
distribution
domestic sewage
dioxins
di-n-butyltin dichloride
daphnids
duckweed
EDTA
estuarine
elimination
effects
evaluation
equilibrium
effluent(s)
ecology
elimination
EHDPP
electroplating
field
fenitrothion
fish
fathead minnow
frog
fuel oil
food
filtering rate
food chain
freshwater
flame retardants

APPENDIX 4 - KEYWORDS USED IN THE ELECTRONIC DATABASE

gut
gastropod(s)
growth
guppies
gills
growth rate

heavy metals
Hyalella azteca
herbicide
hexachlorobenzene
hexabromobenzene
hydrocarbons
herbicide
hexachlorobenzene, HCB

invertebrate(s)
insect(s)
in situ
industrial discharge
industrial waste(s)
indigenous
insecticide(s)
iron, Fe
indicator species
international
inorganic

kidney
kinetics

lab
lead, Pb
life cycle
leech(es)
lamprey
lake acidification
larvae
lobsters
lindane
lake trout

APPENDIX 4 - KEYWORDS USED IN THE ELECTRONIC DATABASE

metal(s)
mercury, Hg
macrophyte(s)
molybdenum, Mo
mining
mussel(s)
mollusc(s) (k)
marine
methoxychlor
model
midge(s)
metal(s)
morphology
metallothionein-like
marsh plants
manganese, Mn
magnesium, Mg
mining wastes
morphology
macroalgae
methyl parathion
monitoring
Mysis relicta
mosquitofish
mechanisms

NTA
nickel, Ni
natural populations
naphthalene
nonylphenol
nonpoint source

organochlorine(s)
oligochaete(s)
organ(s)
on-line
ocean dumping
oils
oyster
organosulfur compounds
octanol/water partition coefficient
organics
octachlorostyrene

polychlorinated biphenyls, PCBs
pH
prawn(s)
pesticide(s)
polynuclear aromatic hydrocarbons,PAHs
particle-size-conversion efficiency
pollution
pulp mill effluent
philosophy
plankton
polychaete(s)
point source(s)
physiological response
phenols
periwinkle
proteins
phenanthrene
pentachlorobenzene
phytoplankton

APPENDIX 4 - KEYWORDS USED IN THE ELECTRONIC DATABASE

rate of
accumulation
radium
radionuclide(s)
resin acids
rainbow trout
reproduction
response
rotifer
road oiling
review
rockbass

sediment(s)
snail(s)
size
selenium,Se
statistics
saltmarsh cordgrass
shrimp
shell(s)
seasonal variation
sublethal effects
sewage sludge
spatial trends
STP
snail(s)
scallops
season
sex
stereochemical
sewage disposal
silver, Ag
season
shellfish
suspended solids
soils
spottail shiners
surveillance
smelter

transplant(ed)
trifluralin
tadpoles
toxicology
toxic organics
tissues
technique(s)
technology
temporal
tubificid worms
temperature
trophic levels
techniques
toxicity tests
TFM
trace elements
temperature
TPP
TCDD

uptake
Ulothrix

worm(s)
water
water quality
water pollution
whelk
water hyacinth
water

APPENDIX 4 - KEYWORDS USED IN THE ELECTRONIC DATABASE

zinc, Zn
zooplankton
  production
Zygnema
zooplankton

APPENDIX 5 - DATABASES USED IN THIS REVIEW.

DATABASE NAME	KEYWORDS USED * combinations were also used	
CEN	bioaccumulation	
	bioconcentration	
	biouptake	
	field	
	biomonitoring	
	bioassessment	
NTIS	bioaccumulation	aquatic organism
BIOSIS PREVIEWS (5,55)	bioconcentration	biota
	biological uptake	plant
	biomonitoring	weed
	bioassessment	fish
	onsite	clam
	field exposure	periphyton
	insitu	artificial substrate
	algae	aquatic weed
	benthic invertebrates	aquatic plant
	field	macrophyte
AQUATIC SCIENCE ABSTRACTS	bioaccumulation	
CONFERENCE PAPERS	bioconcentration	
POLLUTION ABSTRACTS	biological uptake	
	biomonitoring	
	bioassessment	
	field	
ENVIROLINE	freshwater	
ON TAP BIOSIS	clams	
	bivalves	
	metals	
	contaminants	
CISTI	fish	insitu
	leeches	field
	aquatic	onsite
	insects	aquatic organism
	clams	artificial substrates
	bivalves	macrophyte
	molluscs	biota
	caging study	plant
	bioaccumulation	weed
	biomonitor	periphyton
	bioconcentration	biological uptake
	benthic invertebrates	

APPENDIX 5 - DATABASES USED IN THIS REVIEW.

NOTE: manual searches (from 1975 to present) were made of the following journals:

Bulletin of Environmental Contamination and Toxicology
Marine Pollution Bulletin
Marine Biology
Journal Fisheries Research Board of Canada (Canadian Journal of Fisheries and Aquatic Sciences)
Water Research
Environmental Science and Technology
Ecology
Aquatic Toxicology